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Flight Tests of the Air-Launched Balloon System (ALBS) Prototype Model

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Chief Scientist

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The requirements for the Air Launched Balloon System (ALBS) development program and the highlights of that program, prior to the flight test phase, are presented. The rationale behind an ambitious ALBS parachute subsystem test flight series, using C-130 aircraft, at the National Parachute Test Range is given, along with the initial system configuration chosen for that series. The test-demonstrated inadequacy of the 32-ft drogue chute is documented. The successes achieved subsequently in flights with a 28-ft drogue chute (in (over)

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20. Abstract (Continued)

combination with the 42-ft main chute) are described, both for tests employing a dummy balloon and for later tests in which a real balloon was used. Attempts at partial balloon inflation at the NPTR are discussed. The unsolved parachute coning problem is also described, along with tests aimed at its solution. Planning and preflight preparations for the January 1978 balloon drop test over the White Sands Missile Range are covered in considerable detail. The abortive launch of that flight is related and an analysis of the reasons for the flight failure is presented. Five (5) appendices are included with supporting calculations.

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Preface

The test program described in this report is long and complex. When one becomes intimately involved in such an effort for a long period of time, as did the author, one can easily over-identify, to the point where supporting roles become obscured. It is hoped that this did not happen here.

Throughout the report every attempt has been made to give credit to others for their help. The number of people and organizations who rendered assistance to the ALBS program was so great, however, that a special acknowledgments section is in order.

First, the solid and continuous encouragement of the author's parent organization, AFGL, is acknowledged with gratitude and appreciation. From Col. B. S. Morgan, Jr., Commander, on down, there was a steady and timely flow of resources, technical assistance, and logistical support actions, all of which were vital to the success of the program. Mr. Thomas Kelly, Director of the Aerospace Instrumentation Division, and Mr. James Payne, Chief of the Balloon Research Branch were particularly helpful. Mr. Arthur Giannetti and Sergeants Gary Blanchard and George Clement of the Balloon Instrumentation Branch, provided assistance in many ways in addition to furnishing the sophisticated UHF TM/Control Pack. Mr. Thomas Danaher and the members of his Balloon Requirements Branch were understanding and generous in the matter of balloon flight scheduling (including much rescheduling) and the allocation of needed resources. Mr. James F. Murphy and Mr. Don Maltaces of the Operational Services Branch made substantial contributions in the key area of aircraft flight support, and rescued the program on more than one occasion when it threatened to become bogged down. Detachment 1,

AFGL, at Holloman AFB, played a major test role, as described in Section 5 of this report. The author is deeply grateful for the help and dedicated support of Major Joseph Koehly, Detachment Commander; Captain Michael Wilson, Operations Officer; and the many Det 1 noncommissioned officers, civilian and enlisted personnel who participated in the extensive preparations for and the conduct of the Holloman AFB/WSMR Balloon Drop Test. Mr. Willis Parsons of the WSMR was of immense help during the arrangements for Range support and his assistance, also, is acknowledged gratefully.

The Parachute Test Program described in Section 4 could not have been accomplished without the active and willing support of the Air Force Flight Test Center. The author cannot truly express his gratitude to the personnel of the 6511th Test Squadron of the AFFTC, where the test vehicle design, preparation and test planning activities were carried out. Squadron support of the program was total and enthusiastic. The contributions of Mr. Clifford Marshall, Chief Aerial Delivery Section, and of his engineers, Mr. Michael Wuest, Lt. Warren Massey, Mr. Robert Morrison, were outstanding, both at the National Parachute Test Range and in connection with the Holloman AFB/WSMR Balloon Drop. The efforts of the 6514th Test Squadron (AFFTC) at Hill AFB are also acknowledged with gratitude here. The ALBS test program at the NPTR necessitated many long missions for the flight crews of that Squadron. In addition, the author was deeply impressed by, and is very gratful for the support furnished by the Navy and Bell Aerospace personnel at the NPTR. The pilots and photographer's mates who made possible the spectacular air-to-air motion picture coverage of the test flights did a superb job. The Range TM and photograph coverage was also excellent and invaluable for interpreting test events.

A central element in plans for the test program was the availability of a suitable flight-weight cryogenic unit. The role played by the Cryogenics Division of the National Bureau of Standards in Boulder, Colorado in this matter was magnificent. It is really difficult to express adequately the appreciation felt by the author towards Mr. Charles Sindt of the NBS for his contributions to the program. The wholeheated support of the entire Cryogenics Division is an important consideration here and is noted with profound thanks.

A special note of thanks is due to Miss Margo Cross of the Aerospace Instrumentation Division for her valiant struggle to produce a legible manuscript from the author's rough notes, and to Mr. Ed Brennan of the Mechanical Engineering Branch for his assistance in the preparation of Figures 15, 21, and 22.

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1. INTRODUCTION

This is the fourth and final technical report on work performed under AFGL In-House Work Unit (IHWU) 66651101 "Air-Launched Balloon Techniques."*

In the first report, there was a generalized discussion of methods for inflating free balloons in midair following their deployment from a cargo aircraft or from a high altitude rocket.[1] That report concluded that systems employing such methods are capable of being developed and of satisfying several important military needs.

The second report[2] surveyed various kinds of Lighter-than-Air (LTA) vehicles which might serve as high altitude communications relay platforms, discussing operational advantages and disadvantages, and highlighting certain technical considerations. It also reported progress on the Air Launched Balloon System (ALBS) development program, well under way by then, which promised to yield a useful LTA communications relay platform.

(Received for publication 22 March 1978)

*IHWU 66651101 was officially terminated on 30 September 1977. Work performed on the ALBS program subsequent to that date was under successor IHWU 76591101, same title.

1. Carten, A. S., Jr. (1973) An Investigation of Techniques for Launching Large Balloon Systems From Aircraft or Rockets in Flight, AFCRL-TR-73-0633.

2. Carten, A. S., Jr. (1974) An Investigation of the Applicability of High Altitude Lighter-Than-Air (LTA) Vehicles to the Tactical Communications Relay Problem, AFCRL-TR-74-0399.

The third report[3] explored theoretically the dynamics of the ALBS midair deployment sequence, and outlined the proof-of-concept flight tests proposed both to verify those dynamics and to determine system feasibility.

This fourth report covers the flight tests actually carried out on the ALBS prototype system, starting with tests on system mock-ups to qualify the parachute subsystem and ending with the balloon drop test of the complete prototype model.

2. BACKGROUND

2.1 Basic Requirement

The Air-Launched Balloon System (ALBS) under development at AFGL is aimed principally at the requirement for a quick-reaction capability to put a lighter-than-air, tactical communications relay platform into position at high altitudes. Such a requirement is called out in TAC ROC 305-75 entitled, "A Satellite Airborne Communications Relay System for Tactical Air Forces."

For the purposes of the test program reported on here, it was envisioned that the packaged ALBS would be extracted from a C-130 aircraft at 25,000 ft (7.62 km). When the system was properly deployed in midair by a tandem parachute array, the stored ALBS balloon would be extended vertically and filled from an attached helium storage unit. The inflated balloon would then carry the communications relay (approximately 200 lb (890N)) to its assigned altitude ($\simeq$ 70,000 ft (21.34 km)) while the inflation hardware floated to the ground (see Figure 1).

2.2 Previous Development History

In the report entitled "An Investigation of Techniques for Launching Large Balloon Systems for Aircraft or Rockets in Flight," AFCRL-TR-73-0633, it was proposed that a cryogenic gas storage and heat transfer subsystem be used in the ALBS to overcome the severe weight penalties associated with conventional compressed gas storage cylinders. Following the publication of that report, the Cryogenics Division of the National Bureau of Standards (NBS), Boulder, Colorado, carried out experimental research in support of the ALBS program, an effort which led to the design and fabrication of a heavy ground-based prototype cryogenic storage and heat transfer unit.[4] This prototype used a hot packed-bed aluminum oxide (Al_2O_3) heat exchanger to gasify a predetermined quantity of liquid helium and to

3. Carten, A.S., Jr. (1976) The Flight Test Aspects of the Air-Launched Balloon System Development Program, AFGL-TR-76-0196.

4. Sindt, C.F., and Parrish, W.R. (1976) A System for Inflating a Balloon Using Helium Stored in the Liquid Phase, AFCRL-TR-76-0012 NBSIR 76-834.

Figure 1. ALBS Air-Launched Balloon System (ALBS) Drop

warm the gas to a suitable temperature (260°K, average) for filling a balloon. It was successfully demonstrated in July 1975 at Boulder, when a tied-down balloon was filled with approximately 10,000 ft^3 (283 m^3) of gaseous helium in less than 7 min. In November of the same year it was used on the ground at Holloman AFB, New Mexico, to inflate a 145,000 ft^3 (4106 m^3) balloon which, upon being released, carried a payload of 300 lb (1334.4N) to 75,000 ft (22.86 km). This was the first known flight of a large balloon inflated directly from a cryogenic source.

With the basic development tests of the cryogenic unit successfully accomplished, the way was opened for flight tests of the complete system, that is, the dropping of the ALBS "module" or "package" from a suitable vehicle at the envisioned operational altitude, 25,000 ft (7620 m) followed by midair inflation of the system's balloon. Such a test had to be conducted to demonstrate system feasibility, but it was clear from the start that it would be an ambitious undertaking. A special balloon had to be designed and procured, a flight-weight version of the demonstration cryogenic gas storage and heat transfer subsystem had to be constructed and the complicated parachute subsystem had to be tested and qualified. Despite the known problems, plans were initiated in December 1975 for the flight test program.[3]

Early in the test planning process it was decided that the initial drop vehicle for the demonstration ALBS module would be a scientific balloon, even though the ALBS was intended for eventual deployment from an aircraft. This decision was prompted by several considerations,[3] but the overriding factor was the design chosen for the prototype flight-weight cryogenic unit. That design, which had been dictated by project funding and time constraints, was adequate for a balloon drop but did not meet the standards required of equipment carried aboard Air Force aircraft. Thus, the planned tests had to be viewed as proof-of-concept testing, with the understanding that additional drops from a C-130 transport would be conducted at a later date, using a third aircraft-qualified version of the system.

With the basic thrust of the test program thus established, construction of the flight-weight (balloon-qualified) version of the cryogenic unit was begun in the spring of 1976 by the NBS. (See Figure 2 for a view of the completed unit, less superstructure.) The special balloon design needed for midair inflation was worked out at AFGL and an order was placed for three balloons incorporating this design. The parachute subsystem then became the item of major concern. Its importance lay in the key role it was to play both in the aerial deployment of system components, and in the extraction of the folded balloon from its container.

Many computations had been carried out by the author to arrive at a preferred parachute subsystem which could employ available standard parachutes. Although these computations were based, for the most part, on standard parachute formulas, there were some assumptions involved which required verification by actual test. It was imperative that the selected design be proven, using dummy units, prior to risking the expensive cryogenic unit in the balloon drop test. With this consideration in mind, negotiations were undertaken in the summer of 1976 with the Air Force Flight Test Center (AFFTC) for ALBS parachute subsystem test support. They resulted in the establishment of a flight test program at the National Parachute Test Range (NPTR), El Centro, CA under the auspices of the 6511th Test Squadron, with aircraft support from the 6514th Test Squadron at Hill AFB, Utah.

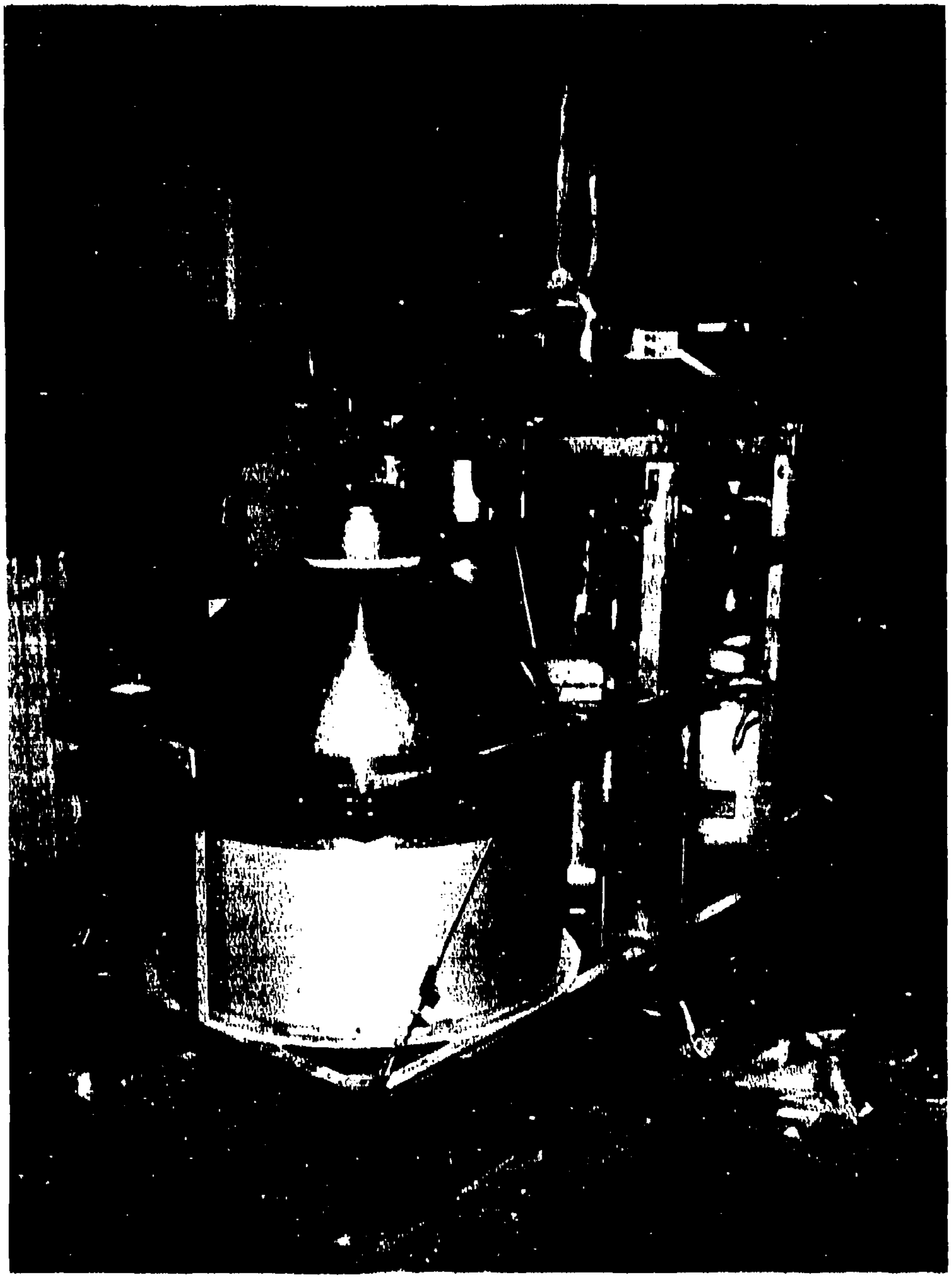

Figure 2. ALBS Cryogenic Inflation Unit, Less Superstructure

Preparations for the parachute test program were begun at El Centro in the fall of 1976, but actual test flights did not get underway until February 1977.* They continued through October 1977 and were followed by the balloon drop test at Holloman AFB in January 1978. The results of these flight tests constitute the bulk of this report.

2.3 Aircraft Test Impact

During the time period covered by the flight tests, a gradual shift in emphasis occurred in the ALBS development program. At the start, the stress was on the balloon drop test aspects, while the aircraft-oriented parachute subsystem tests were perceived as having an important but secondary impact on overall system plans. Then, as the tests proceeded at the NPTR, a role reversal took place. The experience gained from aerial deployments of the dummy system from C-130 aircraft pointed up several inadequacies in the original system design. These ranged from poorly chosen components and unsuitable interfaces between subsystems to the omission of needed hardware items. As a result, the configuration of the prototype to be dropped from a balloon was refined and improved considerably over that described in the third report.[3] (That report, incidentally, had predicted this improvement process.)

The aircraft drops at the NPTR also introduced a major change in the approach initially adopted for the ALBS flight test program. Originally, only a dummy ALBS balloon was to be extracted (extended for midair inflation) at the NPTR. Real balloon extractions were to occur later, in preliminary balloon drops at Holloman AFB. (Those drops, which would not include the cryogenic unit, were to be dress rehearsals for the crucial "live" drop, also at Holloman, in which the cryogenic unit was to be deployed for the first time.) As things turned out, it proved both feasible and highly advantageous to prolong the NPTR tests to include real ALBS balloon extractions and even to attempt partial balloon inflations. Consequently, the scheduled preliminary balloon drops at Holloman AFB were cancelled, and the remaining live drop was rescheduled for a later date.

Test data obtained from the flights involving real balloon extractions at the NPTR were most helpful in eliminating uncertainties associated with the balloon

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*The 6511th Test Squadron had begun construction of a test vehicle in which the simulated payload would be placed at the apex of the main canopy, along with the packed balloon. Then, in December 1976, the decision was made at AFGL to put the payload at the base of the main chute, thus causing a delay for redesign and reconstruction of the test vehicle. (See the addendum to the third report[3] for the rationale behind the decision.) Although this decision solved a pressing technical problem, it necessitated the carrying of the collapsed main chute to altitude after balloon inflation. This, in turn, reduced available payload weight significantly. (See paragraph 5.4.)

drop which was to take place at Holloman AFB. The aerial delivery program at the NPTR had a further beneficial effect: It provided the author and those supporting him a large amount of "hands-on" experience with ALBS aerial deployment hardware and techniques under semioperational conditions. With this experience, it became possible to plan with confidence for the construction and test of the follow-on, aircraft-qualified cryogenic unit.

3. ALBS PROTOTYPE TEST CONFIGURATION

3.1 Initial Version

At the start of the flight test program, the envisioned ALBS prototype configuration was as described in the third report and its addendum.[3] It consisted of:

(a) A flight-weight cryogenic unit (Figure 2)

(b) A special 158,000-ft^3 (4475-m^3) balloon (Figure 3) and its associated container

(c) A lightweight 32-ft (9.8 m) ring slot upper or "drogue" parachute

(d) A 42-ft (12.8 m) ring sail lower or "main" parachute

(e) A 200-ft (61 m) extension line

(f) A simulated electronics payload, and various items of command and control equipment.

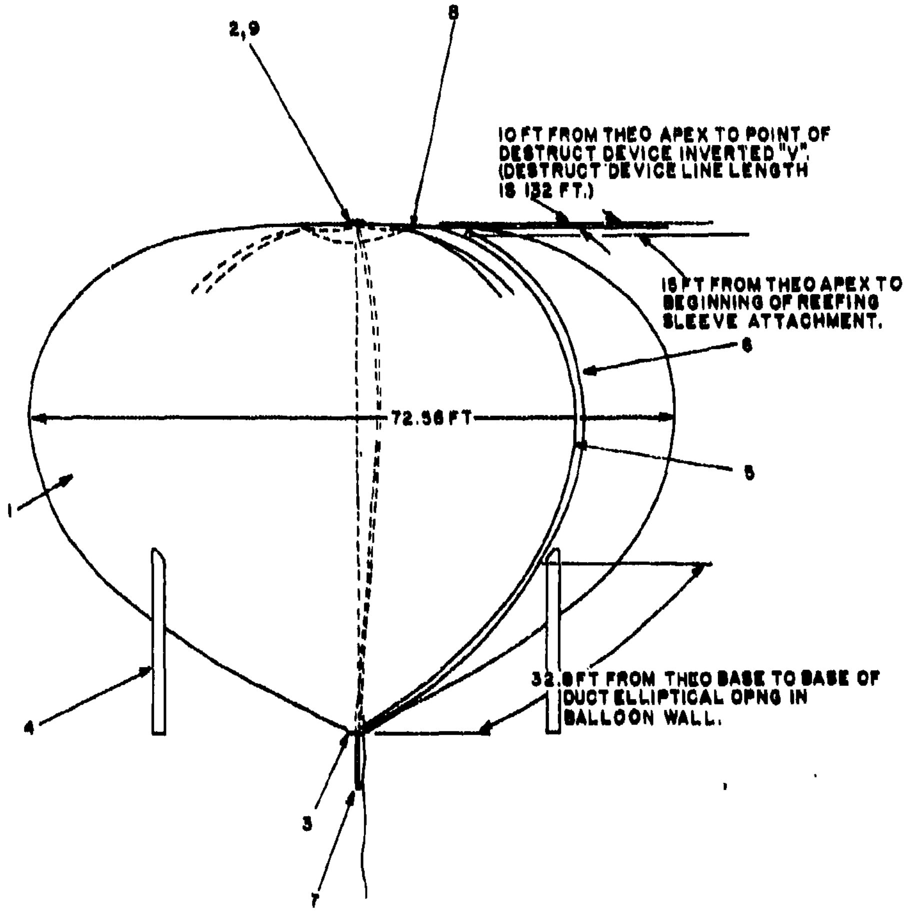
(Note: Details of the interface between the parachute subsystem and the cryogenic unit had not adequately been worked out in the third report.)

3.2 Parachute Subsystem Test Configuration

3.2.1 GENERAL CONSIDERATIONS

A series of about 11 flight tests at the NPTR had been agreed upon between AFGL and the AFFTC. The objective was to show that the configuration described above was feasible; that is, that the chosen parachute system was capable of being launched from a C-130 aircraft and, once launched, was capable of deploying the balloon in midair for inflation. The tests were to be conducted initially at 10,000 ft to allow for crew familiarization with the system. Tests at 25,000 ft would follow this initial phase.

The first problem facing the 6511th Test Squadron, in conducting tests of the ALBS parachute subsystem, was to design an aircraft-droppable test vehicle which adequately simulated the above configuration including those parts which were not actually to be used at the NPTR. (The cryogenic unit, the electronic payload and the ALBS balloon were the most readily identifiable components in this category.) The simulation was to be as realistic as possible with regard to weight, volume,



SYM	QTY	DESCRIPTION
9	1	NAMEPLATE
8	1	DESTRUCT DEVICE ASSY, GORES 13 & 27
7	1	INFLATION TUBE, 107.7 FT LONG, GORE SEAM 20
6	1	REEFING SLEEVE ASSY, GORE SEAM 28
5	1	VALVE CABLE ASSY, GORE SEAM 28
4	4	DUCT ASSY
		DUCT ATTACH, GORES 1, 8, 15 & 22
3	1	BASE FITTING ASSY
2	1	APEX FITTING ASSY
1	1	BALLOON SHELL ASSY (1.5 MIL MAT'L, NO LOAD TAPES)

Figure 3. ALBS Balloon Assembly (Design Volume 0.156 MM Ft^3; Winzen Research Inc. Model SF-72.56-150-TT-01)

length and any other characteristics essential to parachute system performance. Moreover, the test vehicle had to store the packed main chute and simulated balloon internally until they were to be deployed. At the proper staging operation, it had to permit rapid and positive extraction of these components.

The resulting test vehicle was a cubical wooden box open at the top. Four ft (1.22 m) to a side and framed in heavy angle iron, it weighed approximately 665 lb (2958N) empty. A heavy lead plate weighing 365 lb (1624N) was added to bring it up to full system weight.* (See Figures 4 and 5 and also footnote * on page 94 with regard to use of Newtons (N) to note weight in the metric system.)

Note: The 6511th Test Squadron has prepared a technical report[5] on the test vehicle and the ALBS subsystem tests. This report will defer to the 6511th T.S. report with respect to details of box construction and rigging, and will present only that information essential to the purposes of this report.

3.2.2 LOAD EXTRACTION AND DEPLOYMENT STAGES

The launch of the 6511th Test Squadron's ALBS test vehicle from a C-130 aircraft and the subsequent deployment of the system components was planned as a 3-stage operation (see Figure 6). The first stage was to be the load extraction (that is, the pulling of the test vehicle from the aircraft horizontally) and the transition to a vertical attitude. The second stage was to be the deployment of the 42-ft (12.8 m) main chute, 200 ft (61 m) beneath the drogue chute. The third stage was to be the extraction of the simulated balloon from its container on top of the open main chute and the full extension of that balloon, as would be required for midair inflation. This third stage was to be accomplished through the drag forces exerted on the packed balloon by the 32-ft (9.8 m) drogue chute.**

3.2.3 INADEQUACY OF THE 32-FT (9.8 m) DROGUE CHUTE

To reduce system complexity, the drogue chute was chosen to act also as the load extraction chute, a role which subjects the drogue to high loading forces. In this case, the force was taken to be approximately 10,000 lbf (44,480N), a value slightly on the high side. (Actual calculations are contained in Appendix A). There was some question at the start about the ability of the 32-ft light-weight ring-slot

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*The lead ballast and the massive structural members of the cubical box simulated the weight of the cryogenic unit, but being very dense, they did not truly simulate its volume characteristics. This discrepancy was considered unimportant with regard to parachute system qualification testing.

**In the deployment of the real balloon in a live operation, there would be additional stages; the filling of the balloon, the cutting away of the drogue, the dropping away of the cryogenic unit, etc. (See Figure 1.) In the NPTR tests, the plan was to take the operation only through the first three stages, as described above.

[5]Massey, W., and Wuest, M. (1978) The Air Launched Balloon System, AFFTC-TR-77-42.

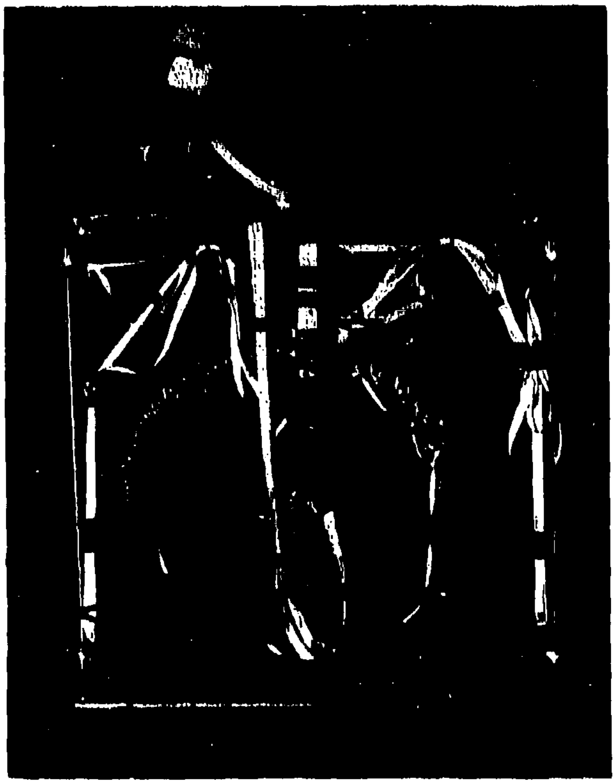

Figure 4. Flight-ready ALBS Test Vehicle, in Horizontal Attitude, With Packed 28-ft Drogue Chute at Top

chute to withstand such forces. The 6511th T.S. had only limited experience with this parachute as a load extraction chute. It was selected for the ALBS tests primarily to accommodate the author's desire for a drogue chute of specific drag characteristics. His chief concern was with the drag force needed to allow the drogue chute to pull the folded ALBS balloon from its container on top of the main parachute and with the dynamic pressure, "q," which the exposed balloon would experience. Calculations showed that the 32-ft ring sail drogue chute, when deployed above the 42-ft main chute, would easily provide both the needed minimum drag force and the desired q of 0.5-1.0 psf (23.94 - 47.88 N/m^2). (See Appendix B.)

In evaluating the 32-ft drogue chute for the additional load extraction role, the Squadron relied on a previous test where this chute had successfully withstood an extraction force of 11,400 lbf (50,707N). Thus, even though the true operating load range of the 32-ft chute was not known, it seemed reasonable to employ it in an

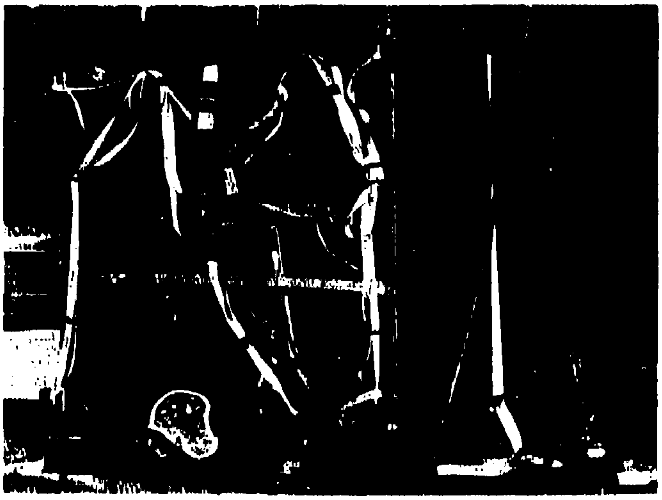

Figure 5. ALBS Test Vehicle Secured to Ramp of C-130, 28-ft Drogue Mounted on Pendulum (Not Shown)

Figure 6. ALBS Test Vehicle Drop at the National Parachute Test Range

extraction where the expected force was at least 1400 lbf (6227N) less than experienced earlier.

3.2.4 THE FIRST ALBS DROP TEST (TEST NO. 1)

The first extraction of the test vehicle from a C-130 took place over the NPTR on 2 February 1977. The aircraft was at 10,000 ft (3048 m), flying at an equivalent airspeed of 130 knots. (True airspeed = 255.5 ft/sec, 77.88 m/sec).* Within seconds of the load extraction, the suspension lines of the 32-ft chute failed and the chute separated from the load. In the resulting free-fall to the desert floor the test vehicle was damaged beyond repair (see Figure 7), thus introducing more than a months' delay into the program for rebuilding of the test vehicle. (The rebuilt test vehicle was actually ready for flight by midMarch. Aircraft maintenance problems delayed the resumption of the test program by another two weeks, however.)

Figure 7. Destroyed ALBS Test Vehicle, Test No. 1

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*True airspeed here is obtained by dividing the aircraft's equivalent airspeed (e.a.s.) in knots by the square root of the density ratio (ρ/ρ_0 or σ) for the altitude at which the aircraft is flying and by multiplying the result by the appropriate conversion factor for ft/sec or m/sec. For example, let e.a.s. equal 130 kt, altitude = 10,000 ft, σ = 0.73859. True airspeed = $130/\sqrt{.73859} \times 1.689$ = 255.5 ft/sec (77.88 m/sec).

On the 2 February flight, the test vehicle had been equipped with strain gauges to measure parachute forces at load extraction and at main chute deployment. Despite the drogue chute failure, a measurement of the peak extraction force was obtained: 10,240 lb, which was somewhat higher than the expected force, 10,000 lbf. Moreover, the actual opening time was measured at 0.88 sec, which should have led to a load more on the order of 9,000 lb. (The reason for the discrepancy was not established.)

Post-flight examination of the drogue chute revealed that the failure had occurred in those portions of the suspension lines near the skirt which had been dyed black approximately one year earlier. (The purpose of the dye at that time was to enhance photographic contrast so that films of the chute opening sequence could better portray the action at the skirt.) On the day following the test failure, tensile strength tests were conducted on both dyed and nondyed portions of the recovered lines. They showed that a marked deterioration in the breaking strength of the lines had taken place in the dyed areas, and that the load capacity of the chute had been seriously degraded. (The specified breaking strength of the lines was 550 lbf (2446N); the measured breaking strength of the dyed samples was only 412 lbf (1833N); nondyed samples broke at or near the specified load.)

This failure incriminated the dyed suspension lines, of course, but it did not bring into question the capacity of the 32-ft chute when not so treated. Even so, it instilled an attitude of caution in this regard. It was decided, therefore, that the next load extraction test would not only feature new, undyed and stronger suspension lines on the 32-ft chute, but also would have that chute reefed 50 percent for 8 sec before full opening, a feature designed to reduce the load extraction force considerably. Moreover, the test would be conducted first with an inert bomb whose weight matched that of the test vehicle. Under this arrangement, chute capability would be demonstrated before deployment of the actual test vehicle, and if the chute failed again, rebuilding of the test vehicle would not be required.

3.2.5 TEST NO. 2

On 29 March 1977, the C-130 took off from El Centro with two loads on board: an inert bomb and the rebuilt ALBS test vehicle. Both were equipped with reinforced, undyed reefed 32-ft (9.8 m) chutes. The bomb was extracted first, from an altitude of 10,000 ft (3048 m) (e.a.s. 130 kt). The 32-ft chute failed immediately and catastrophically. The virtually free-falling bomb buried itself in the desert. Needless to say, the C-130 returned to the base with the ALBS test vehicle still on board.

This time the failure was in the canopy apex area (see Figure 8). High speed motion picture films showed that it had been triggered by an unexplained premature activation of the reefing line cutter after 1 sec. The canopy "blew" when the

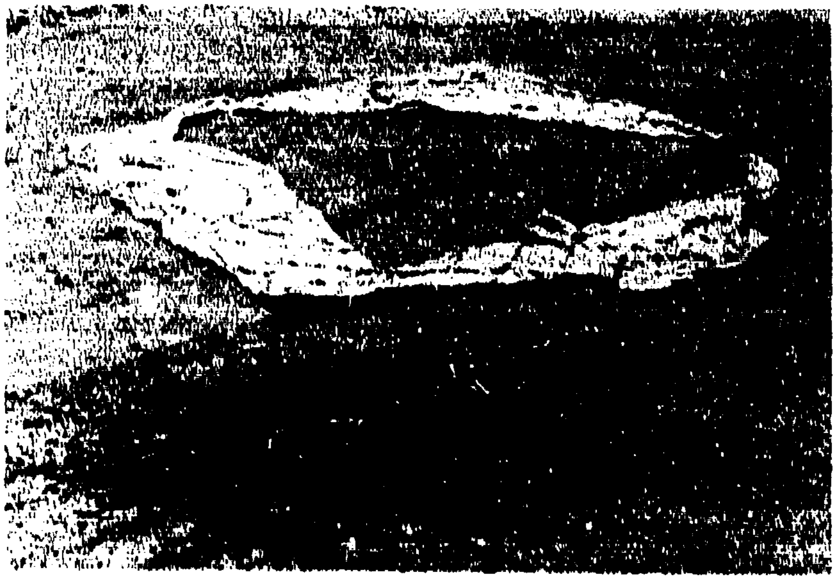

Figure 8. 32-ft Drogue Chute With Apex Area Blown Out

parachute went from 50 percent open to fully open before the system had decelerated significantly. Even so, the chute's inadequacy was clear to all concerned.

After engineering discussions between the author and members of the Squadron, it was decided to abandon the 32-ft (9.8 m) lightweight ring slot chute in favor of a heavier 28-ft (8.53 m) ring slot extraction chute routinely used by the squadron and by Air Force and Army operational elements. (Parachute, cargo, extraction 28-ft FSN 1670-00-687-5459). It has a rated load capacity of greater than 25,000 lbf (1.112×10^5 N). This substitution reduced the amount of drag available for pulling the balloon out of its container, and increased the q (dynamic pressure) that the balloon would experience, but it was a necessary move to get beyond the first step of the ALBS deployment process.

Table B2 of Appendix B shows the calculated values of area, drag and dynamic pressure for the 28-ft drogue chute and 42-ft main chute combination. It indicates that the maximum calculated drag at the drogue (362.69 lbf, 1613.2N) is almost exactly equal to the minimum required value (362 lb, 1610.2N), while the dynamic pressure (1.071 psf, 51.28 N/m^2) is just slightly above the upper limit of the specified range for q. These values indicate a possibly marginal extraction capability and a higher-than-desired force per unit area on the balloon film. As later events showed, however, the disadvantages cited for the smaller diameter chute were of less consequence than had been feared.

3.2.6 FINAL PARACHUTE SYSTEM TEST CONFIGURATION

The decision to use a 28-ft drogue chute restored the test program's momentum and, in the long run, proved to be a good move. It fixed the system parachute sizes and all subsequent tests were conducted with a 28-ft drogue chute and a 42-ft main chute. As the tests proceeded some changes were required in minor system components (break-ties, line cutting devices, etc) which are covered in detail in the 6511th Test Squadron report[5] and are mentioned briefly in this report. Figures 9a and 9b show major details of the parachute system test configuration in the first and second stages of deployment.

3.3 Balloon Drop Test Configuration (Preliminary Discussion)

3.3.1 A DIFFERENCE IN REQUIREMENTS

The NPTR parachute system test configuration discussed above was selected to meet a more limited set of requirements than that of the drop test planned for Holloman AFB, where a carrier balloon would be the platform from which the ALBS module is dropped. In order to verify the dynamics of both the parachute deployment and the ALBS balloon extraction steps, it was not necessary to inflate the ALBS balloon. Hence, a dummy ALBS balloon* could be employed in the NPTR tests as long as it simulated the length and linear weight distribution of the real ALBS balloon in the packed and extended states. Moreover, there was no requirement to separate the dummy balloon from the parachute system during the NPTR tests, even though this is a major requirement when the ALBS balloon is actually inflated (as would be attempted in the Holloman test). The consequence of this difference in requirements was that the NPTR system test configuration could not be used directly in the Holloman carrier balloon drop test. This is not to minimize its importance, however. The NPTR system test configuration did precisely what it was meant to do by qualifying the basic parachute system design. In addition, it provided the engineering foundation for the configuration actually adopted for the carrier balloon drop test.

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*To simulate the real ALBS balloon, which weighs 200 lb (889.6N) and is 102 ft (31 m) long, a dummy balloon was constructed of a double thickness of 9-ply Type XXVI Nylon riser material. The reasoning here was that if the drogue chute could successfully pull this line up from its container at the apex of the main chute and extend it vertically to its full length, the balloon extraction capability of the drogue chute would have been amply demonstrated. (The effect of the dynamic pressure on the real balloon film would have to be ascertained at a later date when the balloon itself would be extracted.)

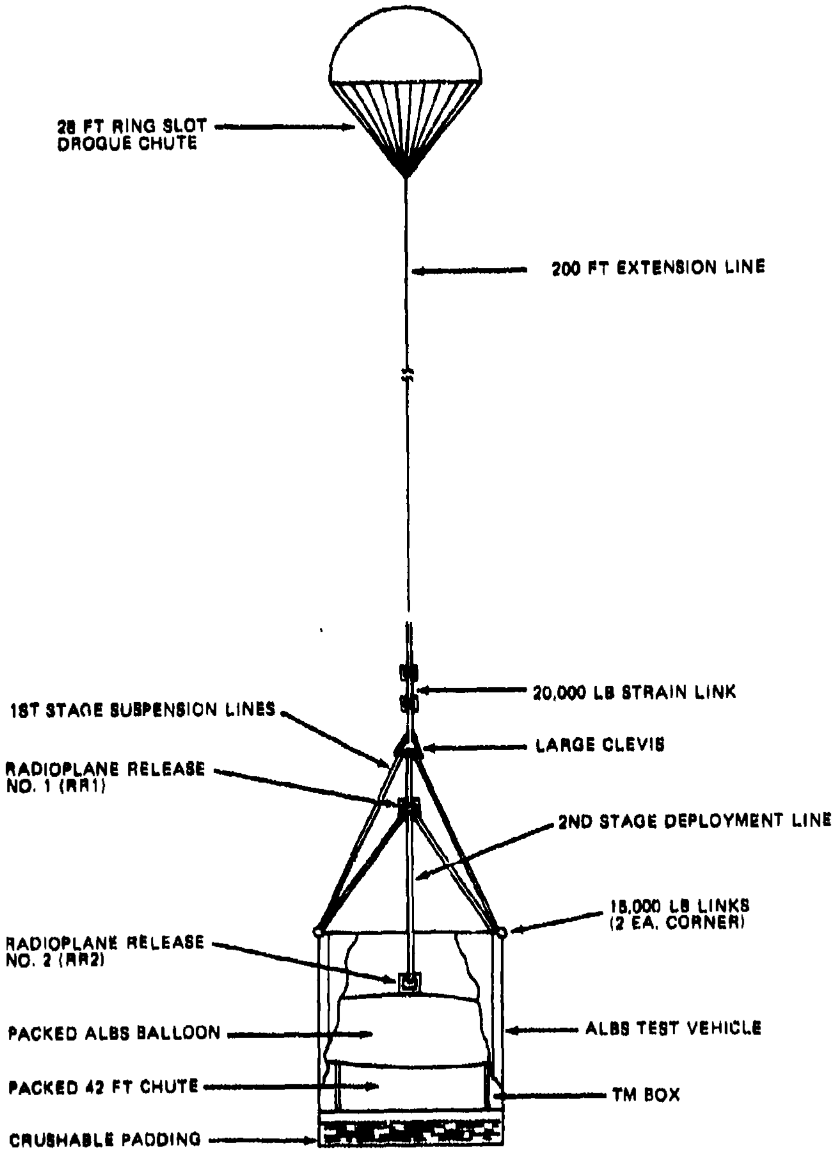

Figure 9a. Parachute System Test Vehicle, First Stage Configuration

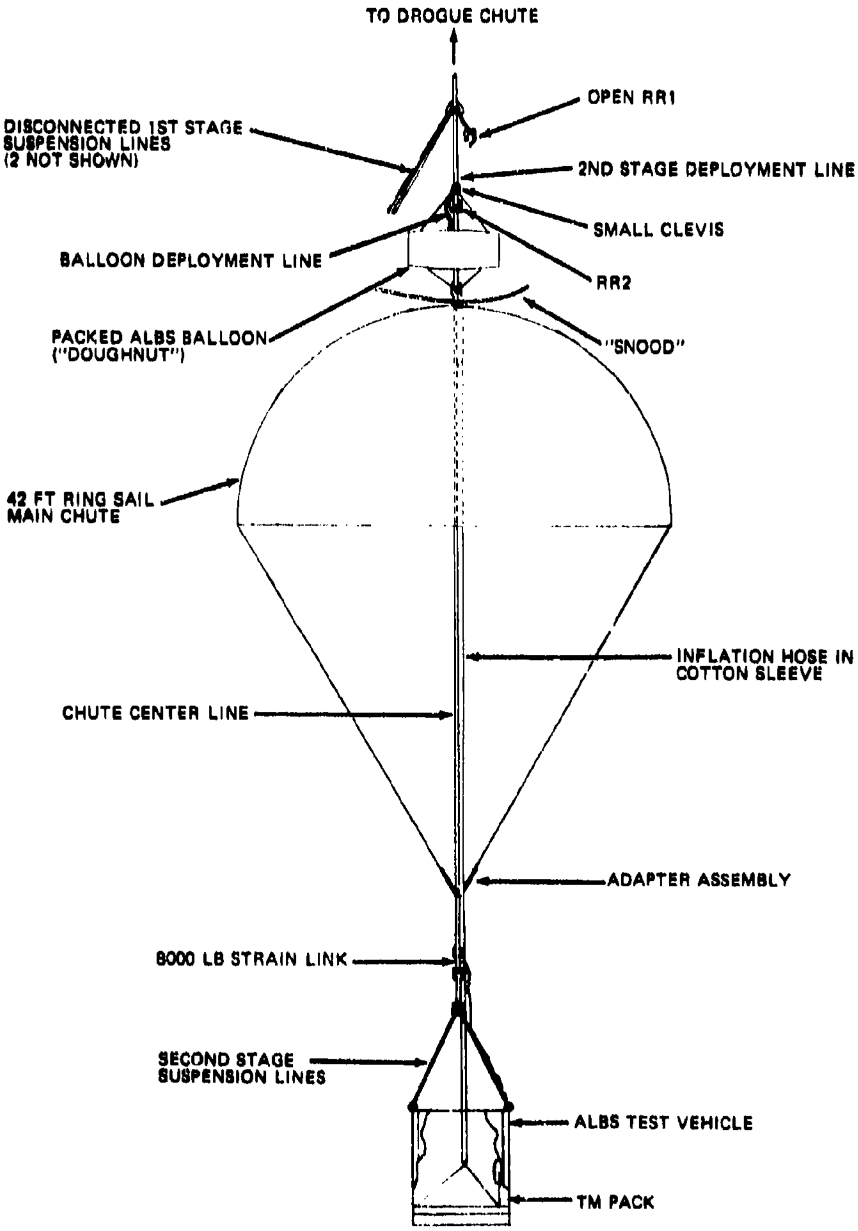

Figure 9b. Parachute System Test Vehicle, Second Stage Configuration

3.3.2 ADDED FEATURES

The carrier balloon drop test configuration, which incorporates a number of additional features, is described in detail in Section 5. It is believed that the reader will better appreciate the subtleties of that configuration after reviewing the narrative account of the NPTR parachute system test program. For that reason, the events connected with the parachute test program will be taken up next.

4. THE PARACHUTE SYSTEM TEST PROGRAM RESULTS

4.1 An Abortive Start

Paragraphs 3.2.3, 3.2.4, and 3.2.5 discussed the shortcomings of the 32-ft ring slot drogue chute and described the first two parachute system tests. No further mention will be made of those tests which were unsuccessful and nonrepresentative of the remainder of the test series.

4.2 A Partial Success (Test No. 3)

On 8 April 1977 the first deployment of the parachute test system configuration with the 28-ft ring slot drogue chute was carried out: At zero time, T_o, load extraction from the C-130 aircraft was initiated and took place flawlessly. (The aircraft was at 10,000 ft, e.a.s. 120 kt).* The test vehicle quickly assumed a vertical attitude, and at T_o + 19 sec, main chute staging was initiated. Six sec later the packed dummy balloon was riding on top of the fully inflated 42-ft main chute (as shown in Figure 9b), waiting to be extracted from its canvas container by the drogue chute. However, when the timer-initiated command for this function was given (at T_o + 39 sec),** there was no extraction. The system floated to earth and landed without damage. Post-flight inspection revealed that the wires leading to the explosive squibs on the number two Radioplane Release (RR2) had been

*The early NPTR flights were performed at 10,000 ft (3048 m) for crew safety purposes. It was believed that the launch crew could gain proficiency with this new system more readily if unhampered by the cold and oxygen-deficient conditions found at 25,000 ft (7620 m). Also, the propeller-driven air-air photographic chase plane (T-28) performs better at lower altitudes. Since this plane would have to bank sharply and continuously to follow the ALBS module down after its extraction from the C-130, it seemed desirable to work out this maneuver first at an altitude of maximum aircraft response. The author agreed, after system calculations established that data gained at 10,000 ft would be applicable to later extractions at 25,000 ft.

**As explained in paragraph 4.3, this time was later changed to T_o + 20 sec and the main chute deployment initiation time was changed from T_o + 19 sec to T_o + 10 sec. The revised times were used for all subsequent tests, including the Holloman AFB drop.

broken during the deployment, thus making the extraction step impossible. (See Figure 10.)

Despite the disappointment over the less than completely successful test, there was elation over both the perfect performance of the 28-ft extraction chute and the positive and unexpectedly rapid (3 sec) inflation of the main parachute. Also pleasing was the lack of damage to the 3-mil (0.0076 cm) thick polyethylene balloon inflation tubing during and after the main chute deployment. (In this test the inflation tube was attached to the main parachute centerline. (See Figure 11.) Later on, it was moved outboard to one of the suspension lines (see paragraph 4.7).)

Appendix C thoroughly covers pre-test calculations of main chute opening parameters, apprehensions felt in connection with the opening and precautions engineered into the system configuration to insure success. This test dramatically vindicated the precautions, verified or refined the calculated results and removed the apprehensions. That the electrical lead wires had failed to survive the moment of violence (see Appendix C, paragraph 3.3.3) when the main chute was deployed, was rightly considered a correctable system design flaw as later events proved.

Figure 10. Radioplane Release No. 2, "Doughnut" and Electrical Connector

Figure 11. Inflation Tubing Assembly. 3-mil layflat polyethylene tubing is inside cotton outer sleeving. Note attachment to centerline of 42-ft main chute

4.3 A Change in the Method of Activating the Radioplane Releases

Discussions between the engineers of the 6511 T.S. and the author led to the decision to try the experiment again with a less vulnerable method of initiating balloon extraction: The battery powered, timer-controlled explosive squibs in RR2 would be replaced with lanyard-initiated, percussion-fired cartridges with a built-in delay of 10 sec. Although reliable and quite commonly used in the aerial delivery of military cargos, these cartridges were not used earlier because of the original long staging times. (Main chute deployment, which is controlled by the first Radioplane Release (RR1) was to be initiated at T_o + 19 sec, while balloon extraction, controlled by RR2, was to begin at T_o + 39 sec.) The test just concluded showed that shorter time stages were possible, thus permitting use of the 10-sec delay cartridges. The 6511 T.S. quickly incorporated them in the ALBS test vehicle both for main chute deployment and balloon extraction (see Figure 12). (See also paragraph 3.4.2, Appendix C.)

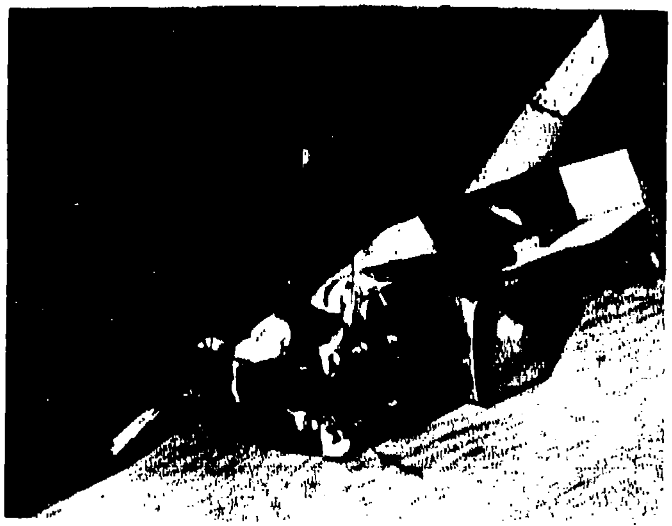

Figure 12. Radioplane Release With Lanyard-Initiated, 10 Sec Delay, Percussion Cartridges

4.4 The Knife That Did Not Cut (Test No. 4)

The next test was conducted on 21 April 1977, with the C-130 flying at the same altitude and airspeed as before (10,000 ft, 120 kt). Load extraction was excellent and the main parachute deployed and inflated properly. Balloon extraction still did not take place, however. Although the percussion cartridges had initiated the extraction step as planned, the event did not go to completion for an unexpected reason:

When RR2 disconnected the drogue line from the apex of the main parachute, the drogue's residual drag force was supposed to pull two cutting knives across the drawlines (lacing) of the balloon containment bag (doughnut) (see Figure 13.) The severed lines would then be pulled from the bag. This action would release the cover of the bag and allow the drogue to pull the balloon upward. What actually happened was that only one knife cut completely through its drawline. The pull of the drogue was insufficient to extract the snagged, longer-than-planned drawline from the doughnut and, thus the balloon was not pulled upward. The array descended to the ground without damage, with the weight of the packed balloon apparently suspended by the nonfunctioning knife's cutting edge.

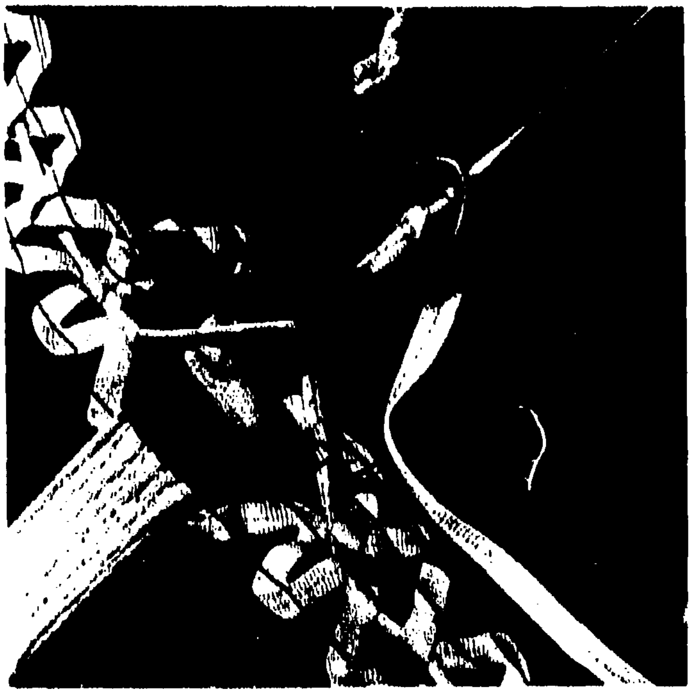

Figure 13. Balloon Containment Bag (Doughnut) Lacing and Cutting Knives

Clearly, another minor design change was called for. The response was to replace the two cutting knives with four explosive reefing line cutters. A 6-sec delay time was included to allow them to be lanyard-initiated during main-chute deployment. Moreover, reefing rings were installed at the top of the doughnut to reduce the friction as the severed drawline was being pulled out. (Nylon loops had been used before.)

4.5 The Retaining Ring Problem (Test No. 5)

The above change was incorporated in the configuration flown on 4 May 77. Unfortunately, a new "glitch" came to light on that date: The load extraction force developed a transverse component which caused the retaining ring for the 3/8 in. (.953 cm) pivot pin (which secures the swing pin of RR1) to fly off. The unrestrained pivot pin immediately fell out, prematurely initiating main parachute deployment. The drogue chute and the 200-ft line were still in a horizontal attitude at this point and the substantial deceleration forces broke the doughnut's restraining straps allowing it to slide along the uninflated main parachute, stopping over the canopy area. When the array swung into a vertical attitude, the doughnut kept the main chute from opening. The fouled lines inhibited balloon extraction also. The array descended to the ground on the drogue chute alone, landing at a very high terminal velocity (approximately 61 f/sec, 18.6 m/sec). The impact was cushioned somewhat by the crushable padding, which was flattened in the process. There was some damage to the rugged test box, but not enough to require rebuilding.

Despite the frustration of the May 4 failure, it was decided to press on. A repeat test was conducted on 11 May 1977, with the faulty grooved pivot pin and retaining ring replaced by a threaded bolt and self-locking nut (see Figure 14).

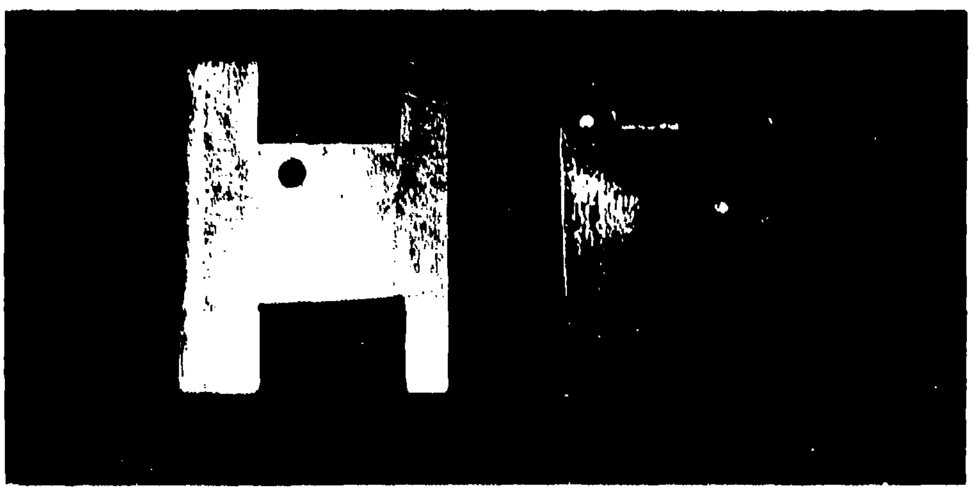

Figure 14. Radioplane Release, Showing Bolted Pivot Pin

4.6 Success at Last (Test No. 6)

Patience was finally rewarded on this occasion. All events occurred on schedule and exactly as planned. The dummy balloon was stretched out vertically to its full length of 102 ft (31.1 m) in approximately 8 sec. The aircraft speed was higher this time, 130 kt, but the higher load extraction forces caused no problem.

With the successful completion of all scheduled events at 10,000 ft, the way was now clear for a test at 25,000 ft. The experience gained in the preceding tests had eased earlier concerns about operating under the harsh, open-cargo-deck environmental conditions at 25,000 ft. As it turned out, the cargo master, photomate, and other cargo deck personnel were able to function quite well.*

It should be mentioned that moderate "coning" of the 42-ft parachute was observed for the first time on the 11 May test flight. This motion, in which the lower part of the main chute and its load rotated through an included arc of about 30 degrees (as opposed to simple back-and-forth pendulum oscillations), was quite noticeable as the array descended to the ground. It gave rise to another system modification described in the next paragraph.

4.7 The First High-Altitude Drop (Test No. 7)

The first drop at 25,000 ft was conducted on 25 May 1977 (airspeed: 130 kts). All stages deployed properly, with no adverse effects due to increased altitude.

In an attempt to reduce or eliminate coning, the hardware at the apex of the 42-ft chute was changed for this test to allow fuller opening of the apex. It was believed that the inflation tubing would not survive the harsher environment at the apex and hence, it was routed up one of the main chute suspension lines and over the top of the canopy for the first time. (Previously, it had been attached to the

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*Actually, the most serious problem encountered in the 25,000 ft launches was the precision flying required of the T-28 photo-chase plane. This called for a learning process on the part of the Navy pilots who flew this aircraft and there was noticeable improvement in the quality of air-to-air photo coverage as the number of releases at 25,000 ft increased. From discussions with these pilots, it was obvious that the tight turning radius needed to keep in contact with the descending ALBS array required maximum coordination and led to substantial physical discomfort. (The same was true of the photomate manning the camera.) At any rate, the air-to-air coverage was truly spectacular towards the end of the flight series. The same improvement was noted in the photography taken from the platform of the C-130, where, even though g-forces were not a factor, ambient temperatures at the open ramp were very uncomfortable. (Part of this improvement was due to a larger camera lens size which experience dictated.) (In addition to the air-to-air coverage just described, the NPTR had several high resolution tracking cameras following the ALBS test events from the ground, plus cine-theodolite coverage for time, distance, height, and velocity measurements, and video cameras for live coverage. The quality of this coverage was uniformly good and made it possible to know at all times what was happening or what did happen during the course of the tests.)

center line.) A swivel was added to the balloon deployment line, as an additional change, to prevent twisting of the drogue from affecting the balloon.

There was no damage in this test to the rerouted tubing. (It was attached in the same manner for the rest of the flight tests.) The fuller opening of the apex did not alleviate the coning problem, however, and it continued to be a worrisome item, eventually leading to the specialized coning tests described under tests no. 12 and 13.

Damage did occur on test no. 7 at the base of the doughnut, however, although it did not interfere with the deployment of the simulated balloon. The culprit was the measured 7000-lbf (3.1×10^4N) shock loading developed during the exchange of momentum between the recoiling doughnut and the suddenly decelerated cryogenic unit. (See Appendix C.) It was decided, therefore, to reinforce the doughnut for the next test. In addition, eighteen (18) Nylon loops, evenly spaced, were added to the centerline of the 42-ft chute. The loops were secured to a restraining steel eye by 350-lbf (1557N) breaking strength ties. It was believed that sequentially-interrupted deployment of the centerline folds would attentuate the shock. (The fact that the inflation tubing was no longer attached to this centerline made such an action feasible.) Thus, a repeat of the 25,000 ft (7620 m) drop was planned using the dummy balloon, the reinforced balloon containment bag, and shock-attenuating ties on the centerline. (See paragraph 4.9 for a description of test no. 8.)

4.8 A Change of Scope

The NPTR test series had been planned to test the dynamics of the parachute system with the understanding that midair deployment of the real ALBS balloon would be carried out for the first time at Holloman AFB. (A scientific balloon would be the deployment vehicle for that test.) However, as the tests at the NPTR progressed, the idea of carrying out the first balloon deployment test there became increasingly attractive. Permission was obtained to add this test to the NPTR series and plans were made accordingly, even while the original test series with the dummy balloon was being carried out. One of the three special ALBS balloons at AFGL was shipped to El Centro for the newly established test. It quickly became apparent that the doughnut would have to be enlarged slightly to accommodate the bulk of the balloon and its large end fittings. Moreover, it appeared that the lower rims of the end fittings would have to be carefully padded to keep them from cutting through balloon material at the time of application of the 7000-lbf force discussed in paragraph 4.7. These were not major changes, however, and it was agreed that the real balloon would be flown after the last scheduled test of the dummy balloon.

4.9 The Final Test of the Dummy Balloon (Test No. 8)

On 17 June 1977, the dummy balloon was deployed from a C-130 over the NPTR for the last time (25,000 ft, 130 kt). All stages functioned properly. The reinforced doughnut was not damaged. The measured deployment shock stayed at 7000 lbf, however, indicating that the 18 Nylon loops were ineffective as shock reducers. In the interest of system simplicity, they were dropped from the configuration and were not used again.

4.10 The Inflation Tubing Question

At this point, it was clear that the actual dynamic performance characteristics of the parachute subsystem matched the requirements established for midair balloon deployment. Interest was now focused on the matter of survivability of the real balloon under the verified dynamic conditions. (Survivability of the rugged dummy balloon was never in question.) However, as plans were being made for the deployment of a real balloon to test its survivability, still another likely problem area came under close review: the adequacy of the inflation subsystem.

The preceding tests had shown that the 3-mil (0.0076 cm) thick inflation tubing could be deployed without damage when attached to one of the suspension lines of the main chute. (It was enclosed in a protective canvas sleeve, see Figure 11.) This fact did not prove, however, that gas from the cryogenic unit would actually pass smoothly up through the deployed tubing and through the interior filling tube in the ALBS balloon. Twisting and kinking of the inflation tubing were seen as distinct possibilities. An obstruction of this type would lead to tubing rupture with the gas escaping to the atmosphere, rather than filling the balloon. Clearly, this aspect of the ALBS process would also have to undergo demonstration testing before confidence could be established in the overall inflation process.

Gradually, a plan evolved whereby a mini-inflation system would be added to the NPTR test vehicle so that a small amount of gas could be passed up to the balloon to verify the suitability of the inflation tubing. This would not be attempted, however, until the real balloon had at least one successful deployment. (See tests 9 and 10.)

The mini-inflation system was to consist of two standard "K" bottles of compressed Helium gas (220 SCF (6.23 m^3) each) which, along with appropriate valves and regulators, would be strapped to the underside of the test vehicle. This system was to match as closely as possible the gas output characteristics of the much larger ALBS cryogenic unit (which could not be deployed from a C-130). The NBS agreed to put such a system together and ship it to El Centro for the planned test (test no. 11).

4.11 First Deployment of the Real Balloon (Test No. 9)

On 29 June 1977, the first deployment of a real ALBS balloon was attempted. The C-130 was at 25,000 ft, 130 kt e.a.s. First and second stage deployments occurred normally and the balloon actually started to move upwards out of the doughnut under the drag of the drogue. Only about a 6-ft (1.8 m) length of balloon was actually pulled out, however, due to the opposing action of an interfering line. The system floated to earth with no damage to the balloon or test vehicle.

4.12 A Successful Balloon Extraction (Test No. 10)

The above test was repeated on 7 July 1977 with the offending line removed from the path of the ascending balloon. Also, four Nylon girdling bands were added around the doughnut pack to control bulk. The results were very gratifying. The entire balloon was extracted readily and suffered no damage either in the extraction or during the descent to the ground. It was clear that the maximum dynamic pressure experienced was well tolerated by the uninflated balloon material. Serious twisting of the inflation tubing between the base of the balloon and the top of the main chute was observed in this test, however, confirming earlier apprehensions on this score.

In prior tests involving only the dummy balloon, the inflation tubing had been tied in several places to the centerline of the 42-ft chute or (later) to one of the suspension lines. Since the dummy balloon had no attachment point for the tubing, the latter was tied off just above the apex of the 42-ft chute. A similar procedure was used at the interface between the test vehicle and the base of the 42-ft chute. This arrangement kept the inflation hose from indicating, by twisting, any relative motion between the dummy balloon and the 42-ft chute. (Twisting at the lower end was not considered a problem and would have been detected from box rotation, if present.)

In the test with the real balloon (test no. 10), however, the top end of the inflation tubing was attached to the flanged inflation port on the bottom end fitting of the balloon. (The bottom of the tubing was still tied off in the test vehicle.) This new connection clearly showed up the twist problem and alerted all to the need for remedial action at once. Twisting of the inflation tubing would cripple the planned mini-inflation test and, thus, could not be tolerated.

Of the many ideas discussed to eliminate the twisting, the one proposed by Lt. Warren Massey of the 6511 T.S. seemed to be the most promising. It involved a flexible no-twist metal linkage system which could be folded in the packing of the balloon and main chute, and which allowed only a quarter-turn of twist between the two. This no-twist linkage (NTL) was fabricated for use on the mini-inflation test flight about to be described. It is depicted in Figure 15, which is a sketch of the

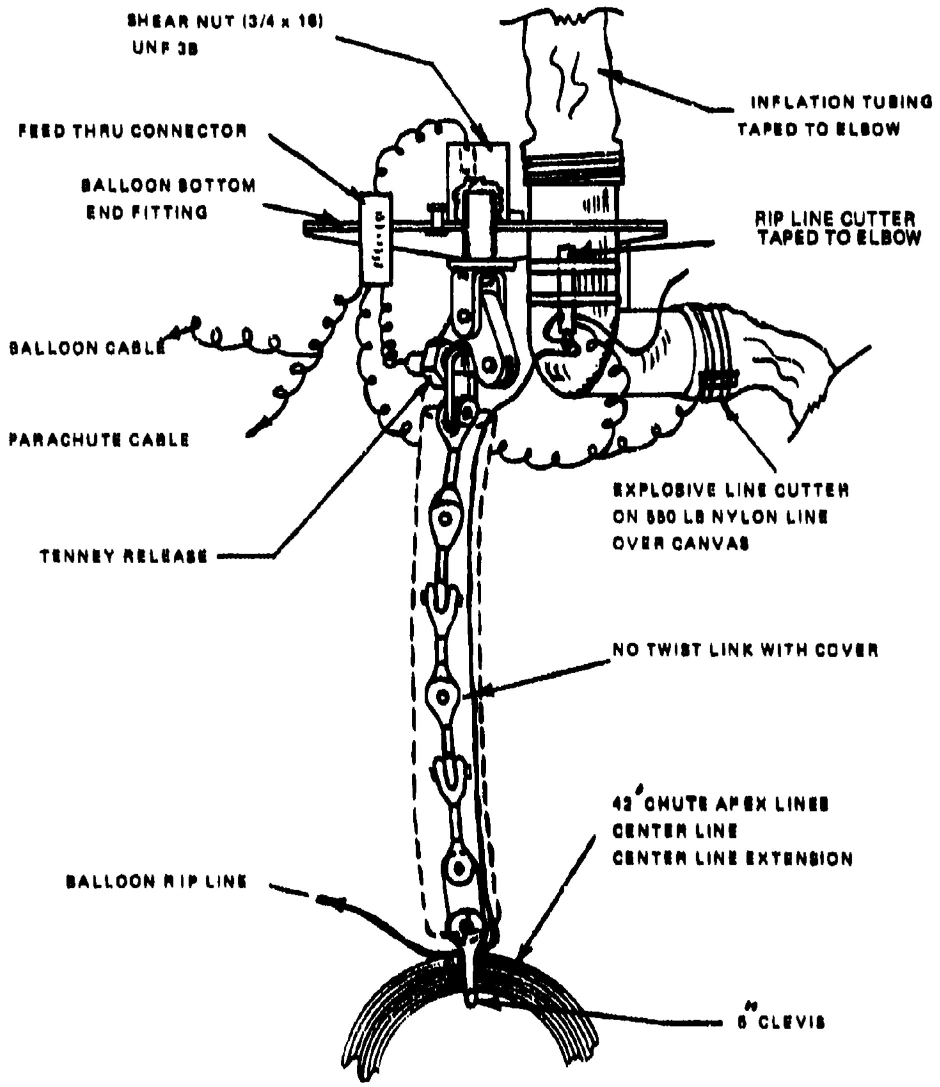

Figure 15. Base of Balloon. No-twist linkage was fabricated for use on mini-inflation test flight

complete complement of hardware items required at the base of the ALBS balloon for a live flight. (This is the configuration actually assembled for the Holloman balloon drop test.)

4.13 The First Attempted In-Flight Inflation (Test No. 11)

On 26 July 1977, the ALBS test vehicle, modified to incorporate the mini-inflation system (see Figure 16) was extracted over the NPTR (25,000 ft altitude, 130 kts e.a.s.). Balloon deployment was accomplished readily and inflation was begun at T_o + 40 sec via a timer-opened solenoid valve. The gas did not appear to have gone into the balloon as planned, however. The films were inconclusive in that they could have been interpreted as showing either a slight inflation or none at all. In addition, the recovered balloon was slightly damaged upon impact with the desert terrain of the NPTR, and one hole near the apex would have released any gas which might have gone into the balloon.

When the recovered inflation tube was examined, several long burst-caused tears were noted in the area which had been just above the test vehicle, that is, at the base of the 42-ft parachute. The test films showed that the inflation tubing, which had been shortened somewhat for this test, might have been stretched taut in that location by a possible 3/4 turn about the 42-ft chute confluence point, thus

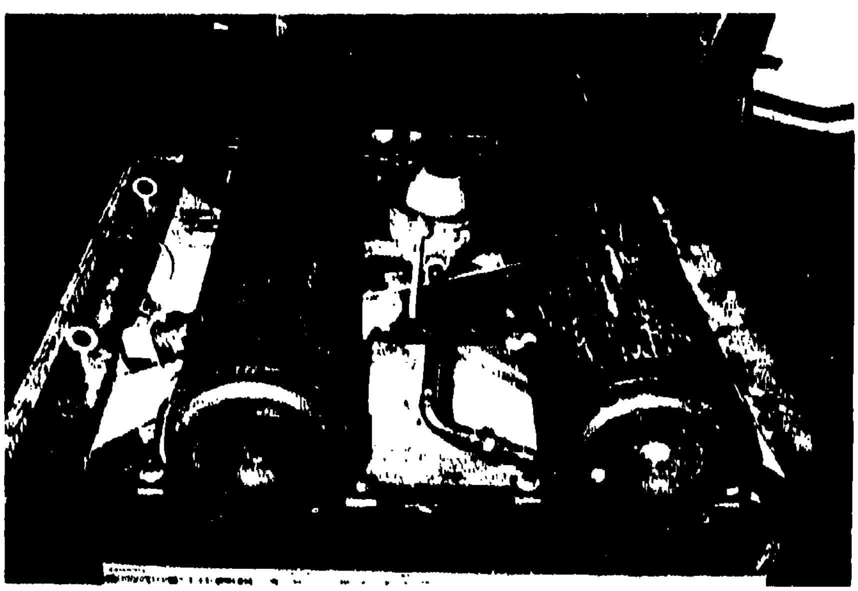

Figure 16. ALBS Mini-Inflation System Bolted to Bottom of Test Vehicle

obstructing the flow of gas and allowing a quick buildup of pressure. Whether this actually occurred could not be determined. It was established, however, by tests conducted later at NBS, Boulder, that the buildup of pressure in the tubing was almost instantaneous (as opposed to the gradual buildup with the cryogenic unit) and that almost any obstruction in the inflation tubing would have led to the burst experienced. It was concluded that the test should be repeated, but only after the mini-inflation system had been modified to provide a gradual pressure buildup which the tubing could tolerate.

The test films also showed that the no-twist link between the apex of the 42-ft chute and the base of the balloon was very effective. The link became a permanent part of the system configuration as a result.

Coning of the 42-ft chute was noted again in this test, and, in the "real time" films of the test, was quite pronounced. (The high speed photography, 100-200 frames/sec, tended to mask this motion.) It was believed that the 42-ft chute centerline was the chief cause of this coning and plans were made to fly two tests of the 42-chute alone, using a 1500-lb (6672N) weight bomb to simulate the test vehicle. One test would be with a centerline, the other without, in order to determine the effect of the centerline. (See tests 12 and 13.) The desire to eliminate coning arose from concern over possible loss of fluid stratification in the cryogenic unit and fear of pinching the inflation tubing off.

As preparations were made for a repeat of the balloon inflation test, other modifications beyond the change in pressure buildup time were worked in. These included adding slack to the inflation tubing, shortening the connection between the main chute and test vehicle, replacing the straight gas inlet pipe on the balloon's bottom end fitting with a large elbow, and fabricating a new, smoother and less bulky canvas protective sleeve for the inflation tubing. The impact-caused holes in the balloon were patched to insure that the inflation gas would be retained.

The planned balloon drop at Holloman AFB (after the completion of the NPTR tests) had been receiving considerable attention during this same time period, and it was decided to incorporate in the upcoming NPTR balloon inflation test some of the items that would be used at Holloman. (These items would be added to test physical compatibility. They would not be functional.) The items included an 8-conductor cable attached to a suspension line of the 42-ft chute and two explosive separation devices (a shear nut and a Tenney load attachment device) at the base of the balloon, as would be required for termination of the ALBS balloon flight at Holloman AFB (see Figure 15). (The 42-ft chute was shipped to Holloman AFB for installation of the 8-conductor cable and was returned to the NPTR for the test.)

In the interest of economy, the two tests to determine the cause of the coning action of the 42-ft chute were scheduled for the same day as the repeat of the balloon inflation test. The C-130 would carry all three drop vehicles simultaneously, releasing the 42-ft chute/weight bomb test packages at 10,000 ft (two passes) and climbing subsequently to 25,000 ft to release the ALBS module. After many delays, this series of drops (tests nos. 12, 13, 14) finally took place on 27 October 1977. The results are described below.

4.14 The Coning Investigation Tests (Tests Nos. 12 and 13)

On the first test (no. 12), the 1500-lb weight bomb was dropped on a 42-ft ring sail chute equipped with a centerline. Definite coning, of the type and magnitude exhibited by the full systems, was noted. Unfortunately, in the second drop (test no. 13), several suspension lines of the 42-ft chute (no centerline) failed, causing the chute to drift. Thus, although no coning was noted, the test was not considered meaningful because of the resultant parachute distortion. These tests proved that the 42-ft chute did indeed cone with a centerline in place, but the parachute's behavior with a heavy load in the absence of that line was not established. The tests were not repeated, for reasons given in the discussion of test no. 14, and as of this writing, the question has not been resolved. (It should be noted here that the 42-ft ring sail chutes used in these tests were new to the 6511th test squadron, and there was little information available on their performance characteristics under various conditions.)

4.15 The Second Balloon Inflation Test (Test No. 14)

The second attempt to achieve partial inflation of the deployed balloon was initiated when the C-130 leveled off at 25,000 ft, after the above coning tests. A problem developed just as the ALBS module was leaving the ramp of the C-130, however, which doomed the test to failure: The deployment of the main chute was initiated prematurely (by approximately 9 sec) so that it opened while still in a horizontal attitude and at a much higher velocity than planned. The shock broke the centerline of the chute, damaged or broke several panels and suspension lines, and tore open a large hole in the partially exposed balloon. Remarkably, the normal two-parachute configuration was subsequently achieved and the balloon was even extracted to full length. The system descended to the ground on both chutes, with the tattered balloon fully deployed.

Post-flight examination showed that the gas inflation system had discharged properly. There was no way of telling whether gas had gone into the balloon, however, because of the many rips in the balloon fabric. Moreover, several long tears where found in the inflation tubing, just below the point of attachment to the balloon's lower end fitting, which, incidentally was badly damaged. It was not possible to tell whether excessive main chute opening forces or gas pressure had split the inflation tubing.

The basic cause of the failure was a matter of speculation. From damage marks noted inside the test box, it appeared that RR1 (see Figure 9a) had struck the bottom side of the box as it was being pulled forward by the taut 200-ft drogue line. The impact was apparently severe enough to break or prematurely discharge the release. (It was never recovered.)

Normally, the load extraction sequence is as follows: The packed 28-ft drogue is released into the airstream behind the C-130 by triggering the pendulum release device on which it is hung. As the chute pack moves away from the aircraft (relatively speaking), deploying the 200-ft line from its base, it develops a downward component which is transferred to the 200-ft line. When the line becomes taut, the 28-ft chute is extracted from the pack lines first, and opens up. The rapidly-developing deceleration force is applied via the 200-ft line to the attachment hardware at the test box, breaking the restraining tie-cords (shown earlier in Figures 4 and 5) and pulling the suspension lines out of the box to form a pyramid. (Figures 17 and 18 show the first stage pyramid in a vertical attitude during pre-flight preparations. In actual flight the pyramid is horizontal, initially. RR1 is near the apex of that pyramid.) When the suspension pyramid becomes taut, the 1000-lb (4448N) restraining line is broken and the box moves out of the aircraft (see Figure 19).

In this case it is suspected that there was a momentary delay in the extraction of the 28-ft chute from its bag at line stretch and an impulse was developed which was translated back to the box on the ramp of the C-130. The downward component of this impulse, in combination with line recoil, apparently caused RR No. 1 to strike a metal fairing on the bottom side of the box with great force, thus initiating the premature release.

This failure was both unanticipated and demoralizing in that it introduced a new uncertainty into the air-launch process. The engineers at the 6511th Test Squadron believed that the configuration used to date could permit the failure just experienced to reoccur on a random basis. Thus, any attempt to repeat the balloon inflation test again would be threatened by the possibility of another failure at the ramp. Extensive engineering and testing would be required, in their opinion, to reduce the chances of such a failure to an acceptable level.

It was reluctantly agreed that the NPTR test flights would be terminated immediately, even though the coning issue had not been resolved and the inflation system had never really been successfully tested. This decision was influenced by a shortage of funds to expand the effort at the NPTR to encompass extraction reliability tests and by a desire to avoid further major slippage of the long-delayed balloon drop test at Holloman AFB. It was reasoned that a successful proof-of-concept test at Holloman would allow the next phase of the program to start, namely the development of the "hardened" version of the cryogenic unit, suitable for extraction

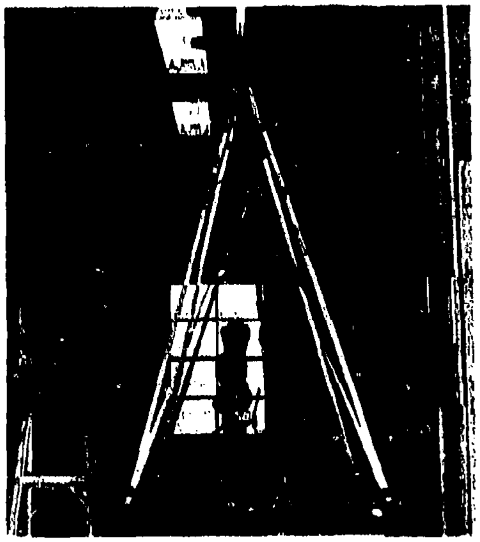

Figure 17. Test Vehicle, First Stage Suspension

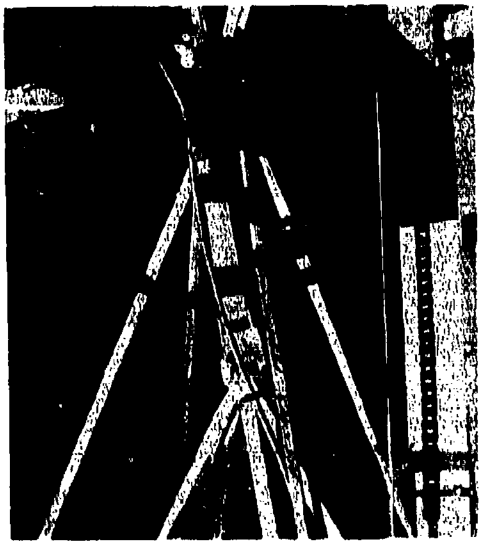

Figure 18. Test Vehicle, First Stage Suspension (Closeup)

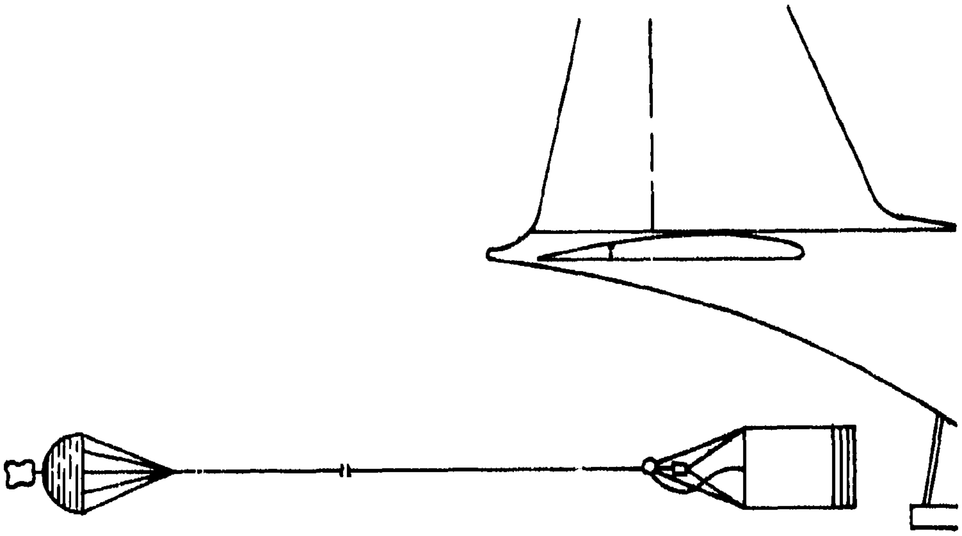

Figure 19. ALBS Load Extraction

Table 1.** Parachute Test Program Summary

Test No.	NPTR OD No.	Altitude MSL (ft)	Airspeed KIAS	Gross System Weight (lb).	Test Date	Remarks***
1	382-77	10,357	130	1510	2-2-77*	32-ft D_o ringslot extraction chute used.
2	518-77	10,000	130	1500	3-29-77*	Weight bomb test of 32-ft extraction chute.
3	413-77	10,560	120	1506	4-8-77*	28-ft D_o ringslot extraction chute used.
4	420-77	10,360	120	1497	4-21-77	RP-1 and RP-2 initiated using pyrotechnic cartridges.
5	611-77	10,140	120	1423	5-4-77	Reefing line cutters installed to cut donut lacing.
6	663-77	10,000	130	1514	5-11-77	Pivot pins in RP-1 and RP-2 replaced with 3/8 in. bolts.
7	612-77	25,000	130	1530	5-25-77*	Apex clevis attachment and inflation tube routing changed.
8	756-77	25,000	128	1530	6-17-77	600-lb break ties used on centerline.
9	757-77	24,950	131	1524	6-29-77	Real balloon used.
10	791-77	25,000	130	1555	7-7-77	Girdling bands attached to donut pack.
11	826-77	25,000	130	1570	7-26-77*	NTL and compressed gas helium system used.
12	122-78	10,000	130	1539	10-27-77	Weight bomb coning test, 42-ft chute with centerline.
13	123-78	10,600	130	1574	10-27-77	Weight bomb coning test, 42-ft chute without centerline.
14	124-78	25,000	130	1534	10-27-77	Elbow added to balloon lower end fitting. Modified compressed gas helium system used. Modified connection between 42-ft chute and SS-2. Modified inflation tube sleeve.

*Indicated Author in Attendance.

**Reproduced from AFFTC-TR-77-42 (Note 6, page 14.)

***See text for test results.

from a C-130. During the development of that version of the ALBS, more reliable extraction techniques would be worked out.

Thus, the program's emphasis now shifted entirely to preparations for the Holloman launch. The engineers of the 6511th Test Squadron were active participants in these preparations and arranged both to furnish many of the components needed for the drop and to be present for the package preparation and post-flight assessment.

With the termination of the NPTR test program, there was some regret that not all of the questions had been answered. Nevertheless, there was a feeling of solid achievement in that the original NPTR flight test objective (see paragraph 3.2.1) had been fully met and that important data had been developed over the above that originally sought. Also, plans for the Holloman drop could be formulated with a degree of confidence in parachute system performance which would otherwise have been impossible.

Note: The foregoing discussion of the NPTR tests gave no indication of attendance by the author. Actually, he made several trips to El Centro during the program, staying almost a month on one occasion. However, despite the best of planning, it was not always possible to forecast the delays and postponements which occurred because of unsuitable weather, aircraft breakdowns, range nonavailability, etc. In the period of a month, he made two separate week long visits to witness a test, which was eventually conducted later in his absence. Fortunately, an excellent rapport was developed with the 6511 T.S. which permitted test preparations and results to be monitored closely by telephone, in lieu of actual attendance. Table 1 summarizes test conditions and indicates tests at which the author was present.

5. THE HOLLOMAN AFB/WHITE SANDS MISSILE RANGE BALLOON DROP TEST

5.1 Prior Preparations

The preceding discussions show that the drop of the live ALBS module from a carrier balloon at 25,000 ft over the White Sands Missile Range had been in the test plan from the start. It was postponed several times because it could not be conducted before the NPTR parachute subsystem tests were completed and they in, turn, were prolonged both by technical problems and by an expanded scope of effort. However, with the termination of the NPTR tests in November 1977, a firm time period for the Holloman test was finally established: 17-20 January 1978.

The broad spectrum of preparations required for this test could not possibly be completed solely within the November to January time period. The January date was chosen only because most of the preparations had been started several months earlier and were actively in progress while the NPTR tests were being conducted. By way of illustration:

(a) The lightweight cryogenic unit had been built and was fully tested by the Spring of 1977 (see Appendix D).

(b) Three (3) of the special ALBS balloons had been procured in 1976 and one of the three had already been deployed in midair several times by the end of the NPTR tests.

(c) The parachute subsystem had been fully qualified at the NPTR, both with a dummy and a real balloon.

(d) An S-Band telemetry module with UHF command and control functions and appropriate sensors had been made up at AFGL for the Holloman flight (see Section 5.4).

(e) The inflation tubing assembly had been fabricated and had been flown without harm on most of the NPTR tests. (Although it had not been fully qualified when those tests ended, the decision was made to use it without change in the Holloman test, with great care taken in its handling and installation.)

(f) The remaining major item was the interface component to tie parachutes, balloon, cryogenic unit, and payload together. Key meetings had been held at the NPTR during the week of 18 July 1977 on the subject of the interface design, with inputs from engineers of the 6511 T.W., the NBS representative, the AFGL telemetry engineer, and the author. The result was the plan for a box-like container (for the packed balloon, the 42-ft main chute, the TM package and the cryogenic unit recovery parachutes) which would be attached to and become a superstructure for the cryogenic unit.* Thereupon, NBS undertook the construction of the

*With this design, main chute deployment and balloon extraction would occur essentially as they had during the NPTR tests using the same staging times. (See footnote ** on page 26.) Then, after drogue release and balloon inflation (stages 4 and 5) had been accomplished, a new 6th staging operation would be accommodated: The cutting away of the cryogenic unit to permit the balloon to ascend. (See footnote * on page 56.)
It is to be remembered here that in the NPTR tests, the 28-ft extraction chute was released to the airstream by the pendulum on board the C-130. As the chute moved out (cf. paragraph 4.15), it deployed the 200-ft extension line and then, as it began to open, it developed enough force to pull the ALBS test vehicle off the aircraft ramp. Subsequently, the system swung through a 90° arc to complete the transition from horizontal to vertical attitude (end of first staging operation).
In the balloon drop test, the ALBS unit stays vertical at all times. As it falls freely it deploys the 200-ft extension line above it which, when taut, pulls the 28-ft chute out of its pack, which is secured to the carrier balloon's load bar (see Figure 20). When the 28-ft chute opens, the balloon-dropped system is in the same same configuration as the aircraft-dropped system at the completion of the first staging operation (see Figure 9a). In both cases, deployment of the main chute (second stage) occurs at $t_0 + 10$ sec.

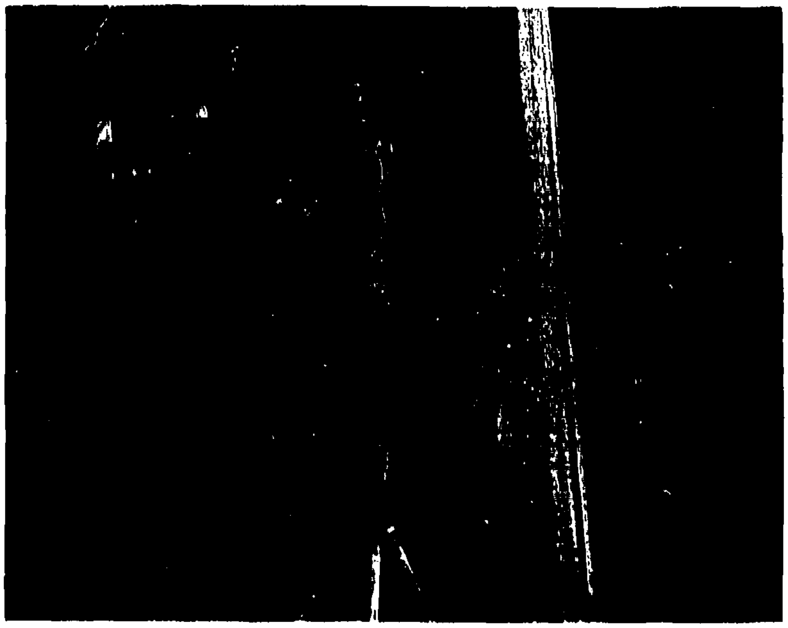

Figure 20. 28-ft Drogue Chute Attached to Carrier Balloon Load Bar

superstructure and mated it with the cryogenic unit at Boulder. By late November, it was ready for shipment to Holloman AFB (see Appendix D).

(g) After the interface method was established in July, the author was able to generate a detailed master sketch of the system (Figure 21 and 22). As he was working on this sketch, which shows the system at the completion of the third stage (balloon extraction), several informal meetings were held at AFGL to resolve questions with regard to such matters as the technique for terminating the flight of the ALBS balloon, the method to be employed for releasing the drogue chute about halfway through the inflation process, and the procedures for disconnecting the inflation tubing, cutting the main chute centerline (see * at bottom of page 56) and dropping away the cryogenic unit at the end of inflation. The answers to these questions, in turn, helped to pin down the specifics of commands to be used, the sequence of those commands, power requirements, cable requirements, and the like. Once these details were resolved, priority was given to ordering, fabricating, or gathering together all of the pieces of required hardware. (As indicated in the discussion of the NPTR tests (see paragraph 4.13), some of the components were even integrated physically into the 6511th T.S. test vehicle to check on their compatibility with the flight components already in use.) By late November, most of the items were on hand or in the final stages of completion.

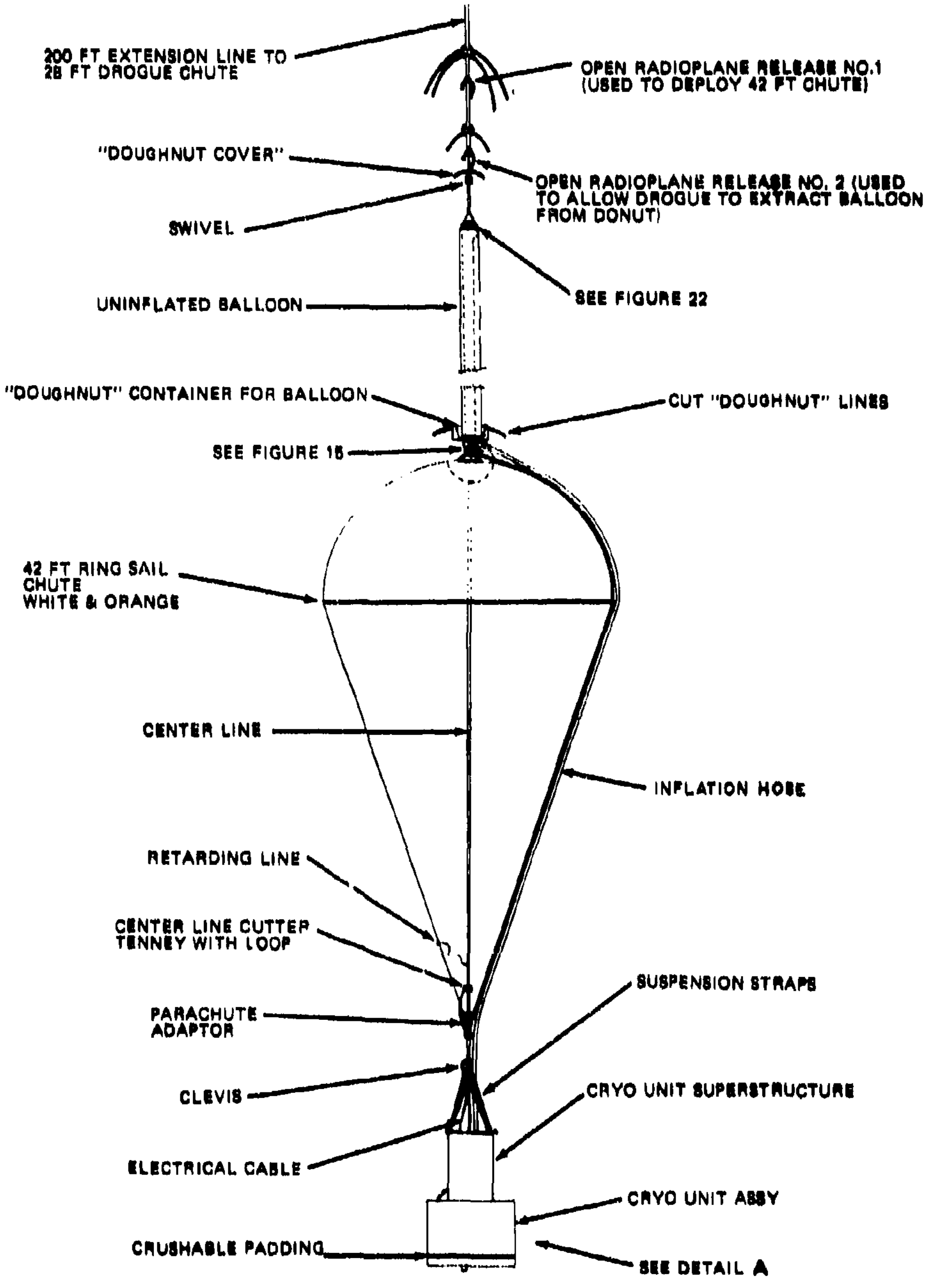

Figure 21a. Outline Drawing ALBS Prototype Configuration for January 1978 Test at Holloman AFB, NM

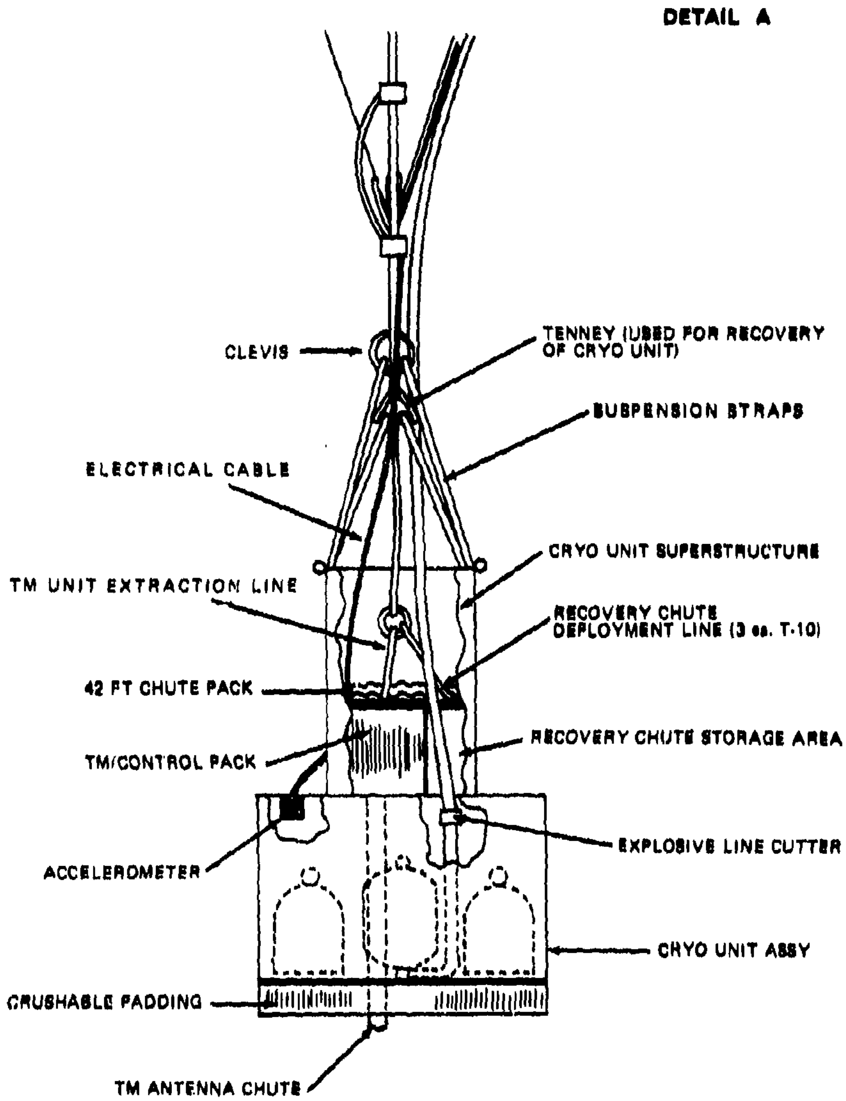

Figure 21b. Outline Drawing ALBS Prototype Configuration - Detail A

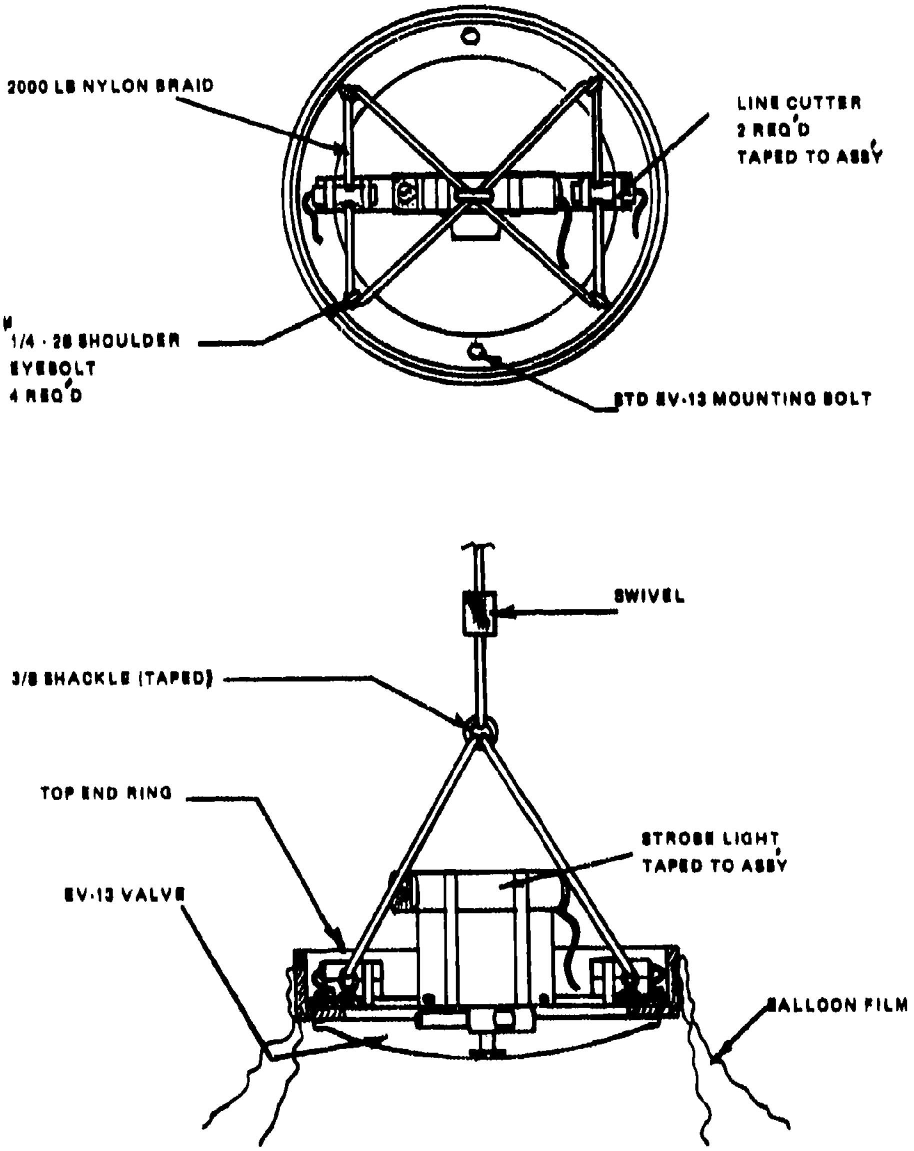

Figure 22. Top of Balloon

5.2 Flight Planning Meetings

5.2.1 GENERAL

When the January date was established for the Holloman drop, it became necessary to make Detachment 1, AFGL, at Holloman AFB an active part of the test team. (Prior to this time, detachment personnel had been in readiness for this call and had been kept fully informed of happenings at El Centro and elsewhere.) The author conducted a series of planning meetings at Detachment 1 during the week of 9 December 1977. A broad range of topics was covered, including test objectives, event sequences and times, potential launch sites, preferred target area, range support requirements, load bar configurations, and Detachment 1 logistical operations in support of a remote launch, if so decided. The NBS representative attended some of these meetings, in addition to checking out the flight-weight cryogenic unit which he had just transported by truck from Boulder. (Fortunately, all components of the cryogenic unit, including the shock-sensitive vacuum systems for thermal protection, survived the trip without harm. The cryogenic unit and its box-like superstructure were left at Detachment 1 to be ready for the January flight.)

5.2.2 THE CHOICE OF LAUNCH SITE

A principal determinant in the choice of launch site was the requirement that the ALBS release be made over a test range. (This requirement arose from the experimental nature of the ALBS deployment process which, in case of failure, would allow the heavy cryogenic unit to descend to the ground at a high terminal velocity, and from the potentially hazardous pressure buildup in the cryogenic unit, if it should land intact and undischarged, with the pressure relief valve jammed shut by impact forces. (See footnote * on page 68.)

Because Holloman AFB, where most Detachment 1 launches are made, is at the eastern edge of the White Sands Missile Range and because the prevailing winds at 25,000 ft over the WSMR in January have a strong west to east component, a launch west of the usual site was initially indicated. Probable flight trajectories were then made up, using January wind fields, and allowing the carrier balloon to climb at 900 fpm to the 25,000 release altitude. They showed that an on-range launch would provide an acceptable flight path only a small percentage of the time, whereas an off-range launch was quite likely to produce the desired trajectory.

Another determinant was the requirement for photo coverage of the ALBS release. The trajectory obtainable from a remote (off-range) launch would position the target area more favorably with regard to normal range telescopic motion picture and video camera locations.

The disadvantages of the remote launch were only too obvious: Several days of per diem costs for ten (10) or more Detachment 1 personnel; the complicated logistics associated with gathering and transporting all the necessary vehicles, supplies and equipment 150 miles to the preferred remote site; the cost of renting temporary facilities at that site; the inability to man recovery crews adequately with the personnel staying behind at Holloman, etc.

The planning meetings resulted in the decision to launch off-range and in the choice of the municipal airport at Truth or Consequences, NM (T or C) as the remote site, a decision which was subsequently approved at the Division level. That site had been used previously by Detachment 1 so that preparations for the remote launch were able to benefit from prior experience.

5.2.3 RANGE REQUIREMENTS DOCUMENT

As a result of the planning meetings, Detachment 1 was able to prepare the Range Requirements document needed to enlist the support of the WSMR photographic, tracking, and communication resources in connection with the planned ALBS drop test. That document, in turn, spawned a WSMR Operational Directive (OD41418A) which outlined the support actually to be provided.

The Range Requirements document (Operation Requirement No. 41418) is reproduced in part here (with minor changes) to summarize the test environment, objectives, and time schedules selected for the planned ALBS test:

5.2.3.1 Program and Mission Information

(a) Test Objectives: The purpose of this program is to air-launch a high altitude research balloon. This will be accomplished by carrying the system to an altitude of 25,000 ft on a carrier balloon. When in position over WSMR, a ground command will initiate the drop sequence. It is anticipated that launch of the carrier balloon will be from Truth or Consequence, NM so that prevailing winds will drive the system over WSMR for the test.

(b) Drop Sequence: It will take approximately 1 hr from launch at Truth or Consequences for the carrier balloon to be in position over the 50 mile area of WSMR at 25,000 ft. When in proper position for optical coverage, a drop command will be issued from the Balloon Control Center at HAFB. The ALBS package consisting of a cryogenic helium unit, a packed 42-ft parachute, packed air launched balloon, and electronic control package will fall from the carrier balloon deploying a 28-ft chute in the process. At T + 10 sec the packed 42-ft parachute is pulled from the container above the cryogenic unit by the 28-ft drogue chute. At T + 20 sec the air-launched balloon (ALB) is pulled from its container atop the 42-ft chute by the 28-ft drogue chute. After the ALB is fully deployed as verified by Detachment 1 airborne observer and/or range TV coverage a start inflation command will be issued by the Balloon Control Center. Inflation will take approximately 5 min.

Thereupon, commands will be issued to release the 28-ft drogue chute* and drop the cryogenic unit on three 32-ft chutes. Both the carrier balloon and the ALB will float at approximately 70 K ft and will be terminated off range, probably east of the Sacramento Mountains. Using standard balloon recovery techniques, all recoveries will be accomplished by Detachment 1, AFGL.

5.2.3.2 Vehicle and Payload Information

(a) Air launch balloon system (ALBS) description: The ALBS consists of a carrier balloon (0.803 MCF) and associated HF control package. Suspended below the load bar by a nylon strap and dual separation devices will be a large wooden box containing the packed air launched balloon, 42-ft parachute, UHF balloon control system for airborne inflation, and three (3) 32-ft parachutes for cryogenic unit recovery. WSMR supplied C-band transponders will be flown on both balloon systems. A packed 28-ft drogue chute will be attached to the load bar and will be deployed at the initiation of the system drop. After ALBS inflation, this drogue will be released by command. The cryogenic unit will also be dropped after inflation and be recovered on three (3) 32-ft chutes. These two items will be recovered on range by Detachment 1, AFGL personnel.

(b) ALBS system weights: Total system weight: 3023 lbs; ALBS weight: 1770 lbs.

(c) Instrumentation: The carrier balloon will utilize an HF command and balloon control package. Telemetry, downlink will also use an HF system. The ALBS will utilize a UHF (420-440 MHz) command package with an S-band (2200-2300 MHz) telemetry system. All balloon commands and telemetry will be accomplished by the Balloon Control Center, Bldg 850, HAFB, NM.

(d) Vehicle description: Both balloons are constructed of 1.5 mil thick polyethylene. The carrier balloon has a maximum inflated diameter of 128 ft and weighs 614 lb. The ALBS has a maximum inflated diameter of 72.6 ft and weighs 190 lb.

5.2.3.3 Vehicle Instrumentation Systems

(a) Each balloon vehicle will be equipped with standard command, control, telemetry, and destruct systems. These systems are provided by AFGL, and operated by the AFGL Balloon Control Center at Bldg 850, Holloman AFB. In addition to providing the routine balloon altitude control functions (ballast drop or helium release), AFGL provides certain command functions to facilitate system drop, inflation start, chute release and cryogenic unit drop. A command and telemetry van, user supplied, will be used at the launch site, T or C airport.

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*Actually, the drogue was to be released at T_0 + 3 min (Author).

5.2.3.4 System Readiness Procedures/Tests

± Time	Event	Action Agencies and Remarks
L - 7 days	Still pictures of payload build-up at Bldg 850	Doc Photo
	Transponder at Bldg 850 for installation on payloads and checkout	WSMR/radar
L - 4 days	Transport payload to launch site Truth or Consequences, NM	User/AFGL
	Install range intercom at launch site	User/Commo
L - 1 day	AFGL aircraft transits range (Alamogordo to T or C airport)	User
L - 6 hr	Begin pibal support at launch site (T or C)	Met
	Still and motion pictures at launch site	Doc Photo
L - 2 hr	Transponder check	User/WSMR radar
L - 60 min.	All stations ready	All
L - 45 min.	Inflate balloon	AFGL
L - 15 min.	Transponder check	User/WSMR
L - 0 min.	Launch balloon	AFGL
	Begin FPS-16 radar track	WSMR/radar
	Radar plot to Bldg 850	WSMR/chain
L + 10 min.	AFGL aircraft take off from T or C	AFGL
L + 1 hr	Balloon in position for drop of ALBS	AFGL
	Optic stations ready	WSMR/optics
T - 5 min.	Begin countdown	AFGL/Balloon Control Center
T - 60 sec	All stations ready for drop	All
T - 10 sec	Digital radar begins FPS-16 No. 1	WSMR/radar
	Start telescope cameras at 100 fps	WSMR/optics
T - 0	ALBS drop	AFGL
	Telescopes follow package	WSMR/optics
	Radar track begins on ALBS (FPS-16 No. 2)	WSMR/radar
T + 10 sec	42-ft orange and white deploys. Telescopes track chute and package	WSMR/optics

± Time	Event	Action Agencies and Remarks
T + 20 sec	Telescope center on top of 42-ft chute for balloon deployment	WSMR/optics
T + 30 sec	Completion of air launched balloon deployment. Telescope center on balloon	WSMR/optics
T + 35 sec	Command inflation begin	AFGL
T + 60 sec	Digital radar complete	WSMR/radar
	Telescope cameras switch from 100 fps to 30 fps	WSMR/optics
T + 3 min.	Telescope center on top of balloon for drogue chute cut	WSMR/optics
T + 3 min.	Command drogue chute cut	AFGL
T + 5 min. 35 sec	Inflation complete	AFGL
	Telescopes center on lower package for cryogenic unit drop	WSMR/optics
	Command cryogenic unit drop	AFGL
	One telescope stay on cryogenic unit until cluster of 3 chutes open, approx 30 sec. One telescope stay on ALB until T + 6 min.	WSMR/optics
T + 6 min. 30 sec	Optics complete	WSMR/optics
T + 3 hr	Terminate carrier balloon off range	AFGL
T + 3 hr, 30 min.	Balloon/payload impact	
T + 3 hr, 45 min.	Terminate ALBS flight off range	AFGL
T + 4 hr, 15 min.	Balloon/payload impact	
T + 5 hr	Mission complete	All

5.3 Choice of Carrier Balloon

During the latter half of 1977, it had been assumed that the carrier balloon would be from the SF128-200-TT series. This balloon model has a nominal expanded volume of 0.803 million ft^3 (22741 m^3) and has a recommended maximum payload capacity of 2200 lb (9786N). It weighs approximately 600 lb (2669N). However, as a result of the planning meetings at Detachment 1 in which the weights of the carrier balloon's load bar, ballast hoppers, range communications packages, and the like were added to the new weights of the ALBS module,* it appeared that the estimated total weight on the carrier would exceed the recommended 2200 lb payload by approximately 225 lb (1001N). (See Table 2.) This raised the spectre of carrier balloon failure. Additional planning meetings at AFGL led to the decision to employ, instead, a special double-walled balloon, model SF 118.66-150 DWR, left over from the earlier POBAL (Powered Balloon) tests at AFGL.

The POBAL balloon is a much heavier balloon, weighing 776 lb (3452N), but it has a recommended carrying capacity of 5,000 lb (22240N). Its expanded volume is 0.711 m ft^3 (20135 m^3). With the enhanced lifting capacity, it was possible to plan for 400 lb (1779N) of ballast instead of the 200 lb (890N) (maximum) permitted with the earlier balloon/payload configuration. The extra ballast would afford greater flexibility in positioning the system over the target area and would aid in the subsequent flight of the carrier balloon to the east, after dropping the ALBS module. Then, unexpectedly, the word was received from Detachment 1 that the only launch arm capable of accommodating the POBAL balloon was out of commission and would not be ready for the January ALBS test. This led to a quick survey of previous flight histories of the 128-200-TT balloon using heavy payloads. The findings are tabulated below (all flights successful):

Flight No.	Payload (lb)	N	Free Lift (lb)	N
H 76-052	2275	10119	283	1259
H 72-077	3800	16902	352	1566
H 68-007	2000	8896	153	681
C 68-001	2996	1332[illegible]	179	796
C 67-018	2996	13326	178	792
C 67-026	2995	13322	143	636
C 67-034	24[illegible]	11102	154	685

As a result of the above histories, the 128-200-TT balloon was reinstated as the carrier balloon for the ALBS drop and the amount of droppable ballast was reduced to the original 200 lb (890N) figure. As shown on Table 2, the tentative payload weight was 2423 lb (10778N); gross weight was 3023 lb (13446N) and with 10 percent free lift, gross inflation was expected to be 3325 lb (14790N).

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*The ALBS module had acquired approximately 250 extra pounds (1112N) of weight as various contingency modifications and reinforcements were added. It was now "grossing out" at approximately 1770 lb (7873N). (See Table 3.)

Table 2. Overall System Weights, ALBS Balloon Drop Test White Sands Missile Range, NM Jan 1978 (Estimated Weights vs Measured Weights

Item	Estimated Weight (lb)	Estimated Weight (N)	Actual Weight Measurements Before Launch (lb)	Actual Weight Measurements Before Launch (N)
ALBS Module and 28-ft Chute	1770	7873	1812	8060
Load Bar, Double Unistrut, (Including All Hardware)	90	400	92	409
Ballast Hoppers (2 ea)	32	142	30	133
Range Pack II, (Minimum Batteries) and Backup Pack	120	534	115	512
C-band Transponder	10	44.5	25	111
Parachute, f.c., 100-ft dia.	201	894	190	845
Durable Ballast, Glass Beads	200	890	200	890
ALBS Release Mechanism	---	---	10	44.5
EV-13, Strobe	---	---	9	40.0
Subtotal a. (Total Payload on Carrier Balloon)	2423	10778	2483	11044
plus Weight of Carrier Balloon	+600	2669	+609	2708
= Subtotal b. Gross Weight at Launch	3023	13446	3092	13753
× 110 percent (10 percent Free Lift) = Gross Inflation	3325.3	14790	3401.2	15129
× 0.97 Correction Factor = Corrected Gross Inflation	3225.5	14347	3299.2	14675

Table 3. ALBS Module Weights, Balloon Drop Test White Sands Missile Range, NM Jan 1978 (Estimated Weights vs Measured Weights)

Item	Estimated Weight		Measured Weight at Launch	
	(lb)	(N)	(lb)	(N)
1. 28-ft Drogue Chute	46	205	46	205
2. 200-ft Extension Line	36	160	36	160
3. Misc. Hardware on Line	20	89	24	107
4. Balloon and Associated Hardware	200	890	230	1023
5. Balloon Pack and Linkage	20	89		
6. 42-ft Main Chute Assembled	125	556	130	578
7. Simulated Comm. Relay	200*	890	200	890
8. Cryogenic Unit, Including Box and Liquid Helium	1003	4461	1079**	4799
9. Recovery Chutes for Cryo Unit	90	400	67	298
10. Ballast	30	133	0	0
	1770	7873	1812	8060

* See para 5.4.

**Includes three Layers of Crushable Padding at Base.

5.4 The Simulated Tactical Communications Relay

The special ALBS balloon procured for this program (Figure 3) had been sized to take a gross load of 575 lb (2558N) to 70,000 ft (21.34 km). This load was originally to be apportioned approximately as follows:

balloon and end fittings	200 lb	890N
tactical communications relay (dummy)	200 lb	890N
expendable ballast	60 lb	267N
recovery chute	35 lb	156N
TM/Control pack	80 lb	356N
	575 lb	2558N

On this basis, the desired lift available from the cryogenic unit during the mid-air inflation was specified and fixed at approximately 633 lb (2816N). This would allow the balloon to support its own weight (200 lb) plus 375 lb (1668N) of payload and to have 10 percent excess lift to insure a normal rate of rise.

As hardware was selected and assembled for the January flight, however, it became necessary to revise the above apportionment drastically. For example, the balloon, strobe light, EV-13 value, termination devices, end linkage and canvas balloon container – all of which had to be taken to altitude – totalled 230 lb (1023N) thus reducing the available payload by 30 lb (133N). A further major reduction had occurred earlier (see footnote * on page 14) as a result of the need to take the hardware-laden 42-ft (12.8 m) main chute to altitude. This chute's weight was measured at 130 lb (578N) as opposed to the 35 lb (156N) originally allocated for a recovery chute. The UHF/S-Band ALBS TM/Control pack also weighed in above the estimated value: 125 lb (556N) vs 80 lb (356N) estimated. These changes led to a tentative new weight apportionment for the January flight:

balloon and attached hardware	230 lb	1023N
42-ft main chute*	130 lb	578N
TM/Control pack	125 lb	556N
ballast	90 lb	400N
	575 lb	2558N

It is clear that, even with the ballast eliminated, that there was no capacity left for a separate 200-lb (890N) dummy communications relay. On the other hand, it was not certain that the sophisticated TM/Control pack**, †, ‡ required for an Research and Development flight would be needed operationally, at least as a separate item. Thus, for this test, it was decided to "create" a 200-lb dummy communications relay by adding 75 lb (334N) of ballast to the 125 lb (556N) TM/Control pack and to fly the following configuration:

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*Includes inflation tube, and 8-conductor cable.

**The UHF/S-Band TM/Control pack was prepared for controlling the midair inflation, release and subsequent flight profile, including termination, of the ALBS balloon. It also telemetered to the ground station the outputs of sensitive accelerometers mounted on the ALBS module. Tables 4a and 4b list the commands and telemetry characteristics respectively. The electronic components were housed on removable rack-mounted panels. That assembly, in turn, was mounted inside a rugged aluminum framework covered with styrofoam insulation and designed to protect the pack against expected ALBS deployment shock loads and subsequent cold-soak conditions at 70,000 ft. Overall dimensions were approximately 25 × 24 × 28 in. (64 × 61 × 71 cm). Four (4) shoulder eyebolts, 1/2 in. dia. (1.27 cm) were added, one to a corner, to facilitate removal of the pack from the box above the cryogenic unit at the completion of the ALBS midair balloon inflation process. (Referring back to Figure 21, note that the TM/Control pack is located at the bottom of the interface box beneath the space previously occupied by the packed balloon and packed 42-ft chute. When the balloon is full and ready for ascent to float altitude, the lines securing the TM/Control pack are cut and it slides upward out of the box and is taken to altitude at the base of the collapsed 42-ft main chute. At the same time, 3 ea. T-10 chutes are deployed from the bottom of the interface box to effect recovery of the box and cryogenic unit. The 42-ft main chute would serve as recovery chute for the simulated relay package upon termination of the flight of the ALBS balloon. This consideration led to the decision to cut the centerline, to insure reopening of the 42-ft chute.)
(Note: Continue footnotes †, and ‡ on page 58.)

Table 4a. ALBS Telemetry Commands (UHF)

Command		Command	
1	TM On	13	10 A, 30 V, Center Line Cut
2	TM Off	14	10 A, 30 V, Inflation Hose Cut
3	0 Cal.	15	10 A, 30 V, Drop Cryogenics
4	2.5 Cal.	16	2 A Gnd, Closure Start Inflation
5	5.0 Cal.	17	2 A Gnd, Closure Spare
6	Spare	18	Ballast
7	Spare	19	Valve
8	Spare	20	Flight Termination
9	Add Time	21	Flight Termination
10	Beacon On		
11	Beacon Off		
12	10 A, 30 V, Drogue Chute Cut		

Table 4b. Air Launched Balloon Telemetry (S-Band)

PCM Word		PCM Word	
1	Sig. Strength	16	Accelerometer No. 3
2	Temperature	17	Accelerometer No. 4
3	Summing Module	18	Accelerometer No. 1
4	0-15 Psia	19	Accelerometer No. 2
5	0-2 Psia	20	Accelerometer No. 3
6	Accelerometer No. 1	21	Accelerometer No. 4
7	Accelerometer No. 2	22	Accelerometer No. 1
8	Accelerometer No. 3	23	Accelerometer No. 2
9	Spare	24	Accelerometer No. 3
10	Spare	25	Accelerometer No. 4
11	Spare	26	Accelerometer No. 1
12	Accelerometer No. 4	27	Accelerometer No. 2
13	0-0.5 Psia	28	Accelerometer No. 3
14	Accelerometer No. 1	29	Accelerometer No. 4
15	Accelerometer No. 2		

balloon and attached hardware	230 lb	1023N
42-ft main chute attached hardware	130 lb	578N
misc. hardware	5 lb	22N
simulated comm. relay	200 lb	890N
	565 lb	2513N

The resultant gross load was kept 10 lb (44.5N) under the planned gross of 575 lb (2558N) to allow for possible minor lift deficiencies in the midair inflation process.

5.5 The Need to Recalculate

5.5.1 GENERAL

The increase in the weight of the ALBS module discussed in paragraph 5.3 cast doubt on the continued validity of system deployment planning figures, which had been calculated in the summer of 1977 on the basis of a 1520-lb ALBS module weight. Consequently, in November-December 1977, a new set of calculations was carried out by the author.

5.5.2 MAIN CHUTE DEPLOYMENT SHOCK

The 7000-lb main chute deployment force calculated in Appendix C, paragraph 3.3.3 (and verified by strain gauge measurements at the NPTR), was the first item checked. This force was recalculated, using the same method as before and substituting a module weight value of 1769 lb. The resulting force value was 8164 lb. Although the g force on the cryogenic unit remained essentially the same

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†An interesting design problem arose here in connection with the TM/Control pack's UHF antenna assembly. The antenna was a small stub arrangement located at the end of a coaxial cable. It had to be kept in line of sight of the ground command station at all times because certain commands (16, 20, 21) had to be capable of being carried out without question from the moment of launch. This meant that the stub had to be located (in the early part of the flight) below the cryogenic unit which otherwise would interfere with the reception of signals from the ground. (Once the cryogenic unit was dropped, the antenna location was not critical.) A wooden chute was devised to solve the problem. It was attached to the cryogenic unit and located under a hole in the large interface box (see Figure 21). The styrofoam encased antenna would be at the base of this wooden chute, and, when the time came to extract the TM/Control pack from the interface box the antenna assembly would be drawn upward out of the chute to follow the TM/Control pack.
This kind of sophistication was needed in the January flight to meet FAA and range safety requirements. It is likely that an operational version of the ALBS would rely heavily on timers for initiating specific functions, thus reducing system weight and complexity.

‡As pointed out in paragraph 5.2.3.3, a different unit was used to control the flight of the carrier balloon and to initiate the drop of the ALBS from the 25,000 ft altitude. That unit was the standard Range Pack II, with a back-up pack. It used HF signals for command/Control and TM. The two packs were mounted on the load bar of the carrier balloon (see Figure 27).

(6g), the shock on the doughnut was increased from 21.1g to 24.2g. This figure was communicated to the 6511th Test Squadron where assurance was given that the balloon containment bag fabricated for the January test had been reinforced and should be able to withstand the increased g load.

5.5.3 SEQUENCE OF EVENTS TABLE

Using the programs discussed in Appendices C and E (The Contracting Spring Program (P-20), the Parachute Opening Program (P4U), the Balloon Extraction Program P-13A, and the Balloon Inflation Program P-14B) recomputations were accomplished for the completion times, forces, and altitudes of the many steps in the ALBS deployment sequence. In general, the changes were not major. The velocities and dynamic pressures were a little higher because of the added system weight of course, but no change appeared capable of affecting the planned deployment significantly.

The revised figures were incorporated in the Range Requirements Document (see paragraph 5.2.3) and are summarized in Table 5.

Note: Table 5 shows balloon inflation beginning at t_o + 28 sec, whereas paragraph 5.2.3.4 shows it beginning at t_o + 35 sec. With the later starting time, inflation sequence altitudes on Table 5 (and on Table E1 in Appendix E) would be reduced by approximately 330 ft.

5.6 Pre-Launch Preparations

The week of 9 January 1978 was selected as the make-ready period for the launch scheduled on Tuesday, 17 January. The goal was to have the assembled payload, all vehicles, and all personnel at Truth or Consequences not later than Saturday, January 14. This would allow two days (Sunday and Monday) for final preparations, a period which would seem to eliminate the need for last minute haste. It would also allow work to be terminated by noon on Monday to permit personnel rest prior to rising at 0100-0200 on Tuesday. This goal was met and all was in readiness for the Tuesday launch.* On Monday, the probable meteorological conditions for Tuesday were reviewed and found to be unfavorable for a

*The final assembly of the ALBS module required a maximum effort on the part of the many people involved. The preparation of the 42-ft main chute was a very time-consuming item. In addition to the tasks of attaching the electrical cable and the inflation tubing assembly to the suspension lines, there was the new task of incorporationg in the 42-ft chute pack Tenney releases for severing the centerline and for effecting cryogenic unit release at the end of inflation. This task had been planned on paper, but accomplishing it physically proved to be an arduous chore. The packing of the balloon in the doughnut was more straightforward, but the details at the top and bottom of the balloon, as seen in Figures 15 and 22, required much time and patience. Perhaps the most difficult chore was the (Continued on page 62)

Table 5. Sequence of Events, ALBS Mid-Air Deployment (Carrier Balloon Used as Drop Vehicle)

Event Number and Description	Event Time (sec)	Cumulative Time (sec)	Event Completion Altitude (ft)	Event Completion Altitude (m)	Event Completion Velocity (FPS)	Event Completion Velocity (MPS)	Remarks
1. Free Fall Phase							HF Command
(a) Release command is given. ALBS components start to free fall, drogue packed; main chute packed, ALBS module weight = 1769 lb (7869N).	0	0	25000	7620	0	0	Lanyards initiate 10-sec delay signal here to deploy 42-ft chute at event 3a.
(b) 200-ft (60.96 m) extension line pays out, becomes taut; pulls static line of drogue chute.	4.0	4.0	(D) 25000 (S) 24800	7620 7559	(D) 0 (S) -113	-34.44	
(c) Drogue chute is pulled out of pack, becomes taut.	1.0	5.0	(D) 24874 (S) 24674	7582 7521	-145 (both)	-44.20	
2. Drogue Inflation							
(a) Drogue chute inflates. (Opening shock 1.8 g.)	2.8	7.8	(D) 24450 (S) 24250	7452 7391	-130.14 (both)	-39.67	
(b) Drogue chute reaches equilibrium velocity (approx).	2.2	10.0	(D) 24254 (S) 24054	7393 7332	-107.6 (both)	-32.80	
3. Main Chute Deployment							
(a) Main chute is deployed. (Shock = 6 g; 24.2 g.)	2.0	12.0	(D) 24114 (S) 23914	7350 7289	-36.09 (both)	-11.00	Lanyards initiate 2nd 10-sec delay here for extraction of balloon (event 4b).
(b) Main chute is opened. (Shock = 2 g.)	3.0	15.0	(D) 23957 (S) 23757	7302 7241	-51.50 (drogue)	-15.70	
(c) Both chutes at equilibrium velocity. (Loads: drogue 422 lb, main 1347 lb or 1877 N and 5991 N.)	5.0	20.0	(D) 23712 (S) 23512	7277 7156	-47.25 (both)	-14.40	
4. Balloon Extraction							
(a) RR2 releases 2nd set of suspension lines, 70 percent of drogue load is transferred to main chute.	0	-	-		-		

Table 5. Sequence of Events, ALBS Mid-Air Deployment (Carrier Balloon Used as Drop Vehicle) (Cont.)

Event Number and Description	Event Time (sec)	Cumulative Time (sec)	Event Completion Altitude (ft)	Event Completion Altitude (m)	Event Completion Velocity (FPS)	Event Completion Velocity (MPS)	Remarks
4. Balloon Extraction (Cont.)							
(b) Drogue pulls ALBS balloon out of container on top of main chute.	6.2	26.2	(D) 23600 (S) 23300	7193 7102	-47	-14.33	
(c) System achieves a new equilibrium velocity.	1.8	28	(D) 23500 (S) 23200	7163 7071	-47	-14.33	
5. Balloon Inflation							
(a) Inflation of balloon begins.	-	28.0	(S) 23200	7071	-47	-14.33	UHF Command
(b) Drogue chute is cut away.	-	180	(S) 17600	5364	-39	-11.89	UHF Command
(c) Balloon inflation ends.		338	(S) 12026	3665	-30	-9.14	NBS timer includes 10-sec delay to bleed cyro unit.
(d) Inflation sleeve is released from cyro unit.		338					UHF Command
(e) Cryo unit falls away.		338					UHF Command
(f) 42-ft chute centerline is cut.		338					UHF Command
6. Balloon Ascends to Float Altitudes	$\simeq$ 60 min	66 min	(S) 70000	21336			
7. Flight Termination							
(a) Separate balloon from chute apex.		$\simeq$186 min	(S) 70000	21336			UHF Command
(b) Release top end, inflation sleeve.							

(D) Refers to drogue chute (28-ft (8.53 m) dia ring slot).
(S) Refers to components mounted on top of main canopy (42-ft (12.8 m) dia ring sail) normally 300 ft below drogue.

launch. A new launch date of Wednesday, January 18 was established. That date was subsequently changed to Thursday, January 19, because of another unfavorable weather forecast. On Wednesday, the forecast for the following day was favorable, and the Truth or Consequences personnel were told to initiate launch preparations early Thursday morning.

5.7 Launch of the Carrier Balloon

The launch crew was at the T or C launch site by 0145 on the morning of 19 January 1978 (scheduled launch time was 0700). An hour later, the ALBS module and all of the other flight components were hung on the load bar and the latter was suspended from the crane to be used in the launch. (Allowing for 5 ft (1.52 m) of clearance under the payload, the distance from the ground to the attachment point on the crane was approximately 30 ft (9.14 m).) (See Figure 27.) Normal equipment checks and command checks were then carried out successfully. The dewars of the cryogenic unit were filled (Figure 28). Gas computations were made and checked for a gross load of 3092 lb (13.753N) (see Table 2). Inflation of the balloon was delayed somewhat, however, commencing at 0643. At 0704 word was received at the Detachment 1 Control Center at Holloman AFB (the assigned mission location of the author, as project officer) that the inflation had been interrupted for a short period to repair a tear in the inflation tube. Inflation was completed at 0729, amidst comments from the launch crew that the balloon appeared to have an abnormal shape (Figure 29). (Later analysis indicated that the unsymmetrical shape noted was normal for the 128T balloon.) Launch occurred at 0734.*

At first, the balloon started to rise normally. Then it settled down (Figure 30) and the payload bumped along the ground. "Pour Ballast" commands were given by the launch officer. After 45 sec of ballasting, at a rate of 34 lb (151N) per

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assembly (for the first time) of the packed balloon and main chute to the cryogenic unit superstructure along with the TM/Control Pack and the 3 T-10 recovery chutes. This turned out to be a measure-and-cut operation, particularly with respect to the installation of the many required restraining lines and deployment lines. Figures 23-26 illustrate some of the assembly operations. The cryogenic unit itself had come from Boulder preassembled and required only the addition of a few minor components. The major task with respect to the cryogenic unit was the filling of the dewars and the heating of the packed bed of aluminum oxide. These tasks were accomplished at the T or C site. (See Appendix D.)

*Cloud cover conditions had begun to deteriorate during the balloon inflation operation. As first light approached, it was reported that a high altitude overcast was present over T or C. Conditions at the Balloon Control Center were also worrisome. There were two layers of broken clouds which threatened to reduce or eliminate effective camera coverage of the release. However, as the sun rose higher in the sky, the clouds at Holloman began to dissipate. At 0730 the coverage was 3-5 tenths of broken altocumulus clouds. The decision was made to launch anyway, even though photo coverage might be degraded. (The forecast for the next day, which proved to be accurate, was for stormy conditions.)

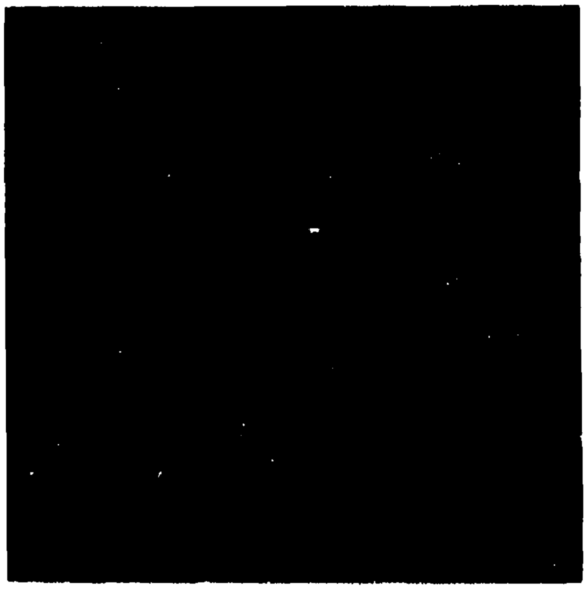

Figure 23. Assembly of Components at Base of Balloon. See Figure 15 for component identification

Figure 24. Assembly of Tenney Releases for Cutting Centerline of 42-ft Main Chute and for Cryogenic Unit Separation. Note inflation tubing assembly at left

Figure 25. Packing of ALBS Balloon in Containment Bag (Doughnut). Top of balloon is at upper left

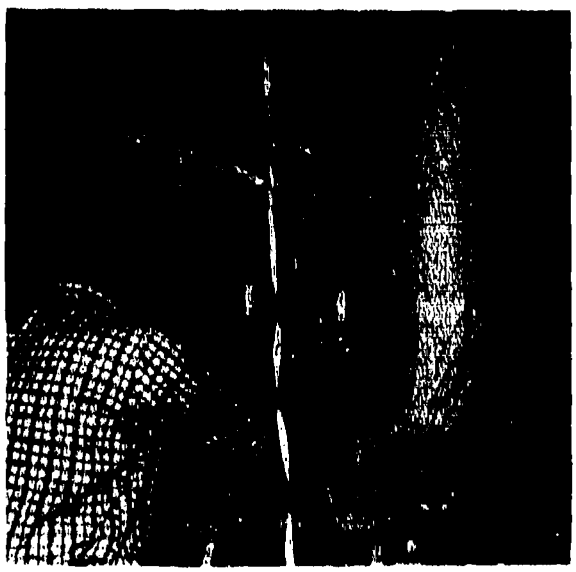

Figure 26. Attachment of Packed Balloon Containment Bag (Doughnut) to Packed 42-ft Main Chute Assembly

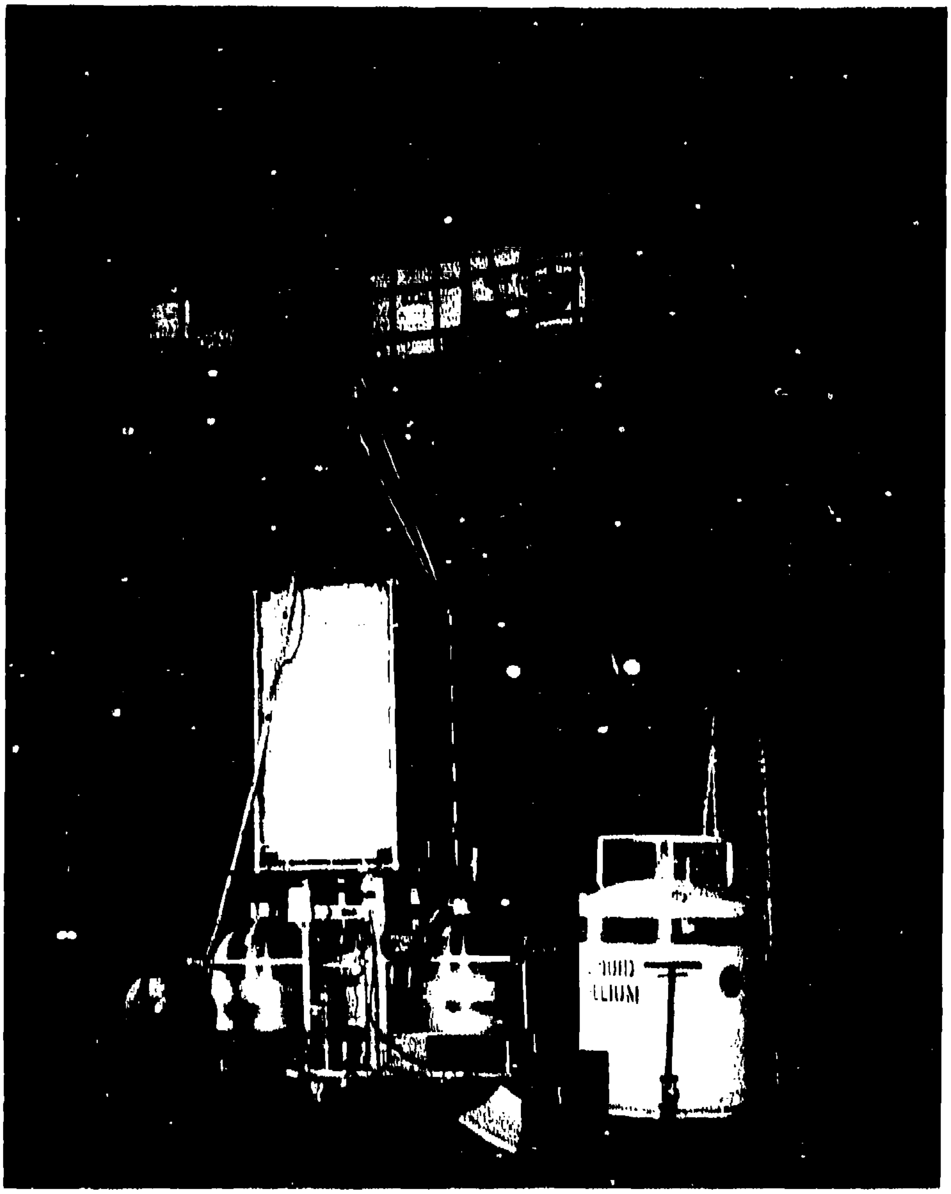

Figure 27. ALBS Module Suspended From Carrier Balloon Load Bar. Other load bar components are: left to right, ballast hopper, C-band transponder, 28-ft drogue chute, range pack II, back-up pack and ballast hopper

Figure 28. Venting of Filled Cryogenic Unit

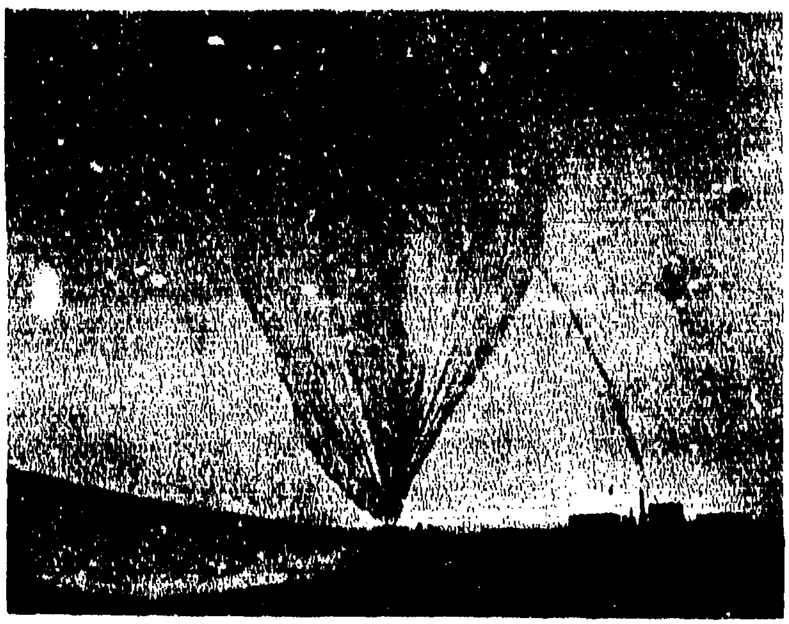

Figure 29. 128-200-TT Carrier Balloon at Inflation

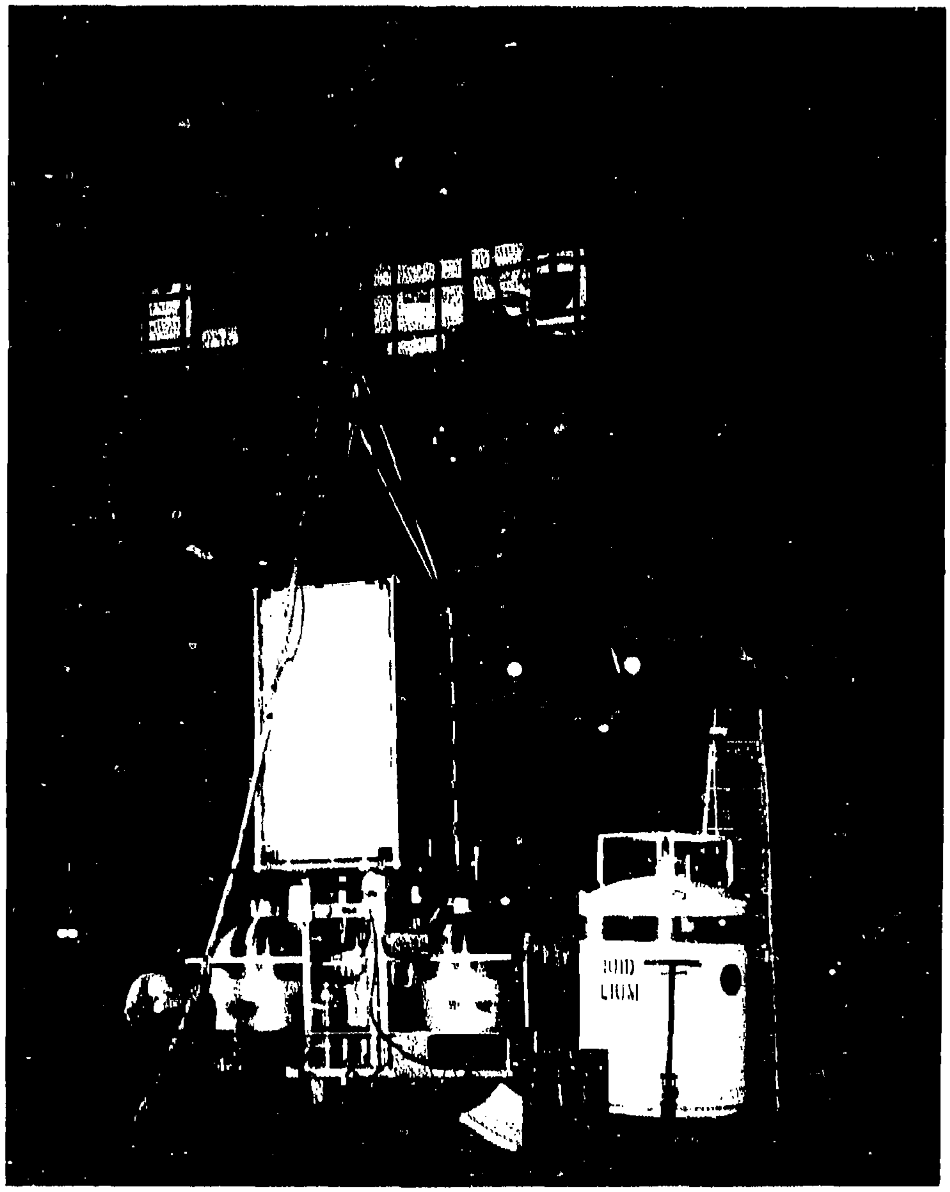

Figure 27. ALBS Module Suspended From Carrier Balloon Load Bar. Other load bar components are: left to right, ballast hopper, C-band transponder, 28-ft drogue chute, range pack II, back-up pack and ballast hopper

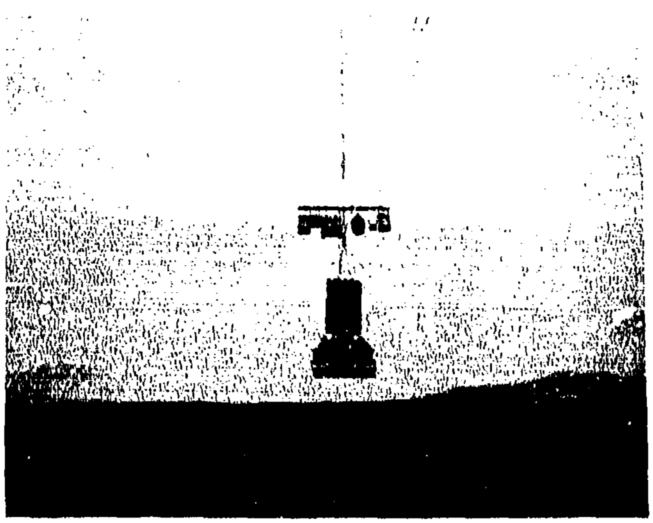

Figure 30. ALBS Module and Load Bar Components Settling to Ground

minute, the balloon was still only 3 to 5 ft (0.9 to 1.2 m) off the ground. (Some of the glass beads being used as ballast were actually falling into the top of the ALBS module and, thus, not reducing the gross load.) The balloon and payload were now drifting eastward. (There was no communication back to the Balloon Control Center during this crisis.) The launch officer, suspecting that he had a leaking balloon, and fearing that the payload would be carried down into a deep gulley at the edge of the T or C airport, or might even be carried over to Interstate Highway 25 to the east, commanded that the flight be terminated via the HF command channel. This caused a double action to occur:

(1) The residual ballast (approximately 175 lb (778N)) was dumped all at once, restoring positive buoyancy to the carrier balloon which began to rise quickly.

(2) Twenty sec later, the carrier balloon and the unopened in-line 100 ft dia (30.5 m) safety parachute were separated at the apex of the parachute.

The ALBS module was approximately 70 ft (21.3 m) off the ground when separation occurred. There was insufficient time or space for the 100-ft chute to be effective and the ALBS module essentially fell freely to the ground. The compressive loading of 17 to 20g was too much for the vertical support members of the cryogenic unit, and they buckled under the weights of the loaded superstructure (approximately 850 lb (3789N)) and the load bar (approximately 375 lb (1668N)).

Figure 31 shows the damage to the cryogenic unit. The dewars were crushed so badly that they had to be scrapped.*

Figure 31. Crushed ALBS Cryogenic Unit

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*Prior to the launch, the matter of cryogenic safety had been discussed at great length. Although the unit was equipped with a pressure relief valve (70 psi), a remote possibility existed that the valve could be made inoperative in a crash if the unit landed in a certain way. In that condition, the dewar tanks (if they had remained intact) would explode when the temperature raised the internal pressure above the design pressure (250 psi). To eliminate this possible hazard, the decision was made that the cryogenic unit would be activated not only in the event of a successful deployment of the system at altitude, but also in all cases of failure. The idea was to have the cryogenic unit land fully discharged. In the incident just described, the "Start Cryogenic Unit" command was not given. It would not have been effective even if it had been given, however, because full discharge requires 5 min and, in this case, the unit was on the ground about 23 sec after the termination command was given. The crash ruptured the dewar connections and the helium vented off through the broken lines for about 50 min after impact. All personnel stayed clear until venting had stopped.

The load bar was badly bent, but the components hung from it were salvageable (Figure 32). The cryogenic unit superstructure was moderately damaged but repairable. The components mounted inside the superstructure (42-ft main chute, balloon, TM pack, T-10 recovery chutes) survived surprisingly well and in many cases suffered no apparent damage.

It was later determined that the balloon was not leaking at the time of launch. It had simply been underinflated. The probable cause of the failure was human error — failure to open the prescribed number of tubes on the helium trailer, a failure which, unfortunately, went undetected. A lift check at the launch arm indicated underinflation, but this sign was not acted on effectively because of known calibration problems with the scale in question.

It is ironic that the ALBS module was destroyed in this way. Had this type of launch failure (very rare) been anticipated, a simple contingency plan would have been rehearsed and made ready for use: Exercise the HF "Experiment Drop" command while the ALBS module is on or just above ground level. (This would have left the module on the ground, while the balloon and load bar rose.) Alternatively, if the launch officer had known that he had an underinflated balloon, rather than a "leaker" as he supposed, he could have continued to ballast at the regular rate or even have dumped all the ballast by the "Blow Ballast" command. This would have allowed the flight to be conducted pretty much as planned (without the controls normally afforded by ballasting), or at least to have been terminated in such a way that the unit would come down on the 100-ft chute with empty dewars.

5.8 Impact of the Launch Failure

The unexpected and catastrophic loss of the one-of-a-kind cryogenic unit had a severe impact on the ALBS program. It closed out the current flight test series abruptly, leaving many questions unanswered. All milestones, subsequent to the January flight test date, had to be cancelled, pending the making up of a new plan of action.

As of the date of this report, plans have been made to develop a "hardened" follow-on ALBS module suitable for an aircraft drop. The details of the revised system configuration will be the subject of another report.

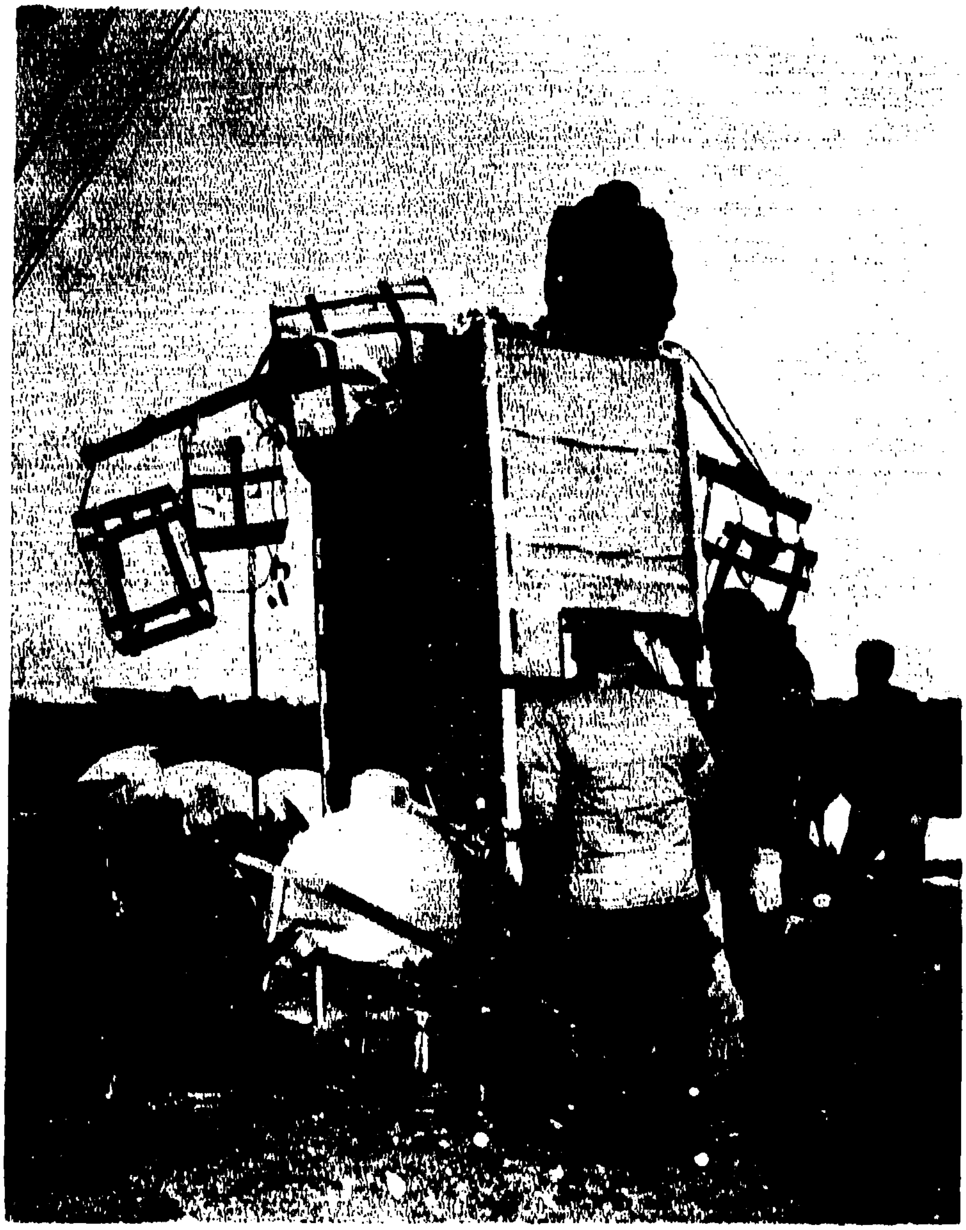

Figure 32. Bent Load Bar Atop ALBS Module

6. SUMMARY AND CONCLUSIONS

This report has described the preparations for and the results of the successful ALBS parachute subsystem qualification tests at the National Parachute Test Range in 1977. It has given the details of the complicated configuration selected for the live drop test of the complete ALBS prototype over the White Sands Missile Range in January 1978. The events leading up to the WSMR test are related, and the unfortunate launch incident which led to destruction of the ALBS prototype is recounted. Computations and analyses in connection with various aspects of the flight test program are given in the Appendices to this report.

It is the author's conclusion that much useful knowledge relevant to the stated goal of the ALBS program has been acquired in the testing accomplished to date. Not all of the questions were answered (coning problem, midair inflation, system effectiveness, etc.) but on the other hand, there were no indications that the original goals cannot be met with continued development and testing.

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Appendix A

Load Extraction Force Computations

1. INTRODUCTION

The method for determining the deceleration or drag forces generated during the extraction of the ALBS test vehicle from the C-130 delivery aircraft is that employed by the 6511th Test Squadron, AFFTC for incompressible flow. It is described in AFFTC-TIM-75-5.[1] The author of that technical memorandum, Mr. Herbert Seaman, was most helpful in explaining his method and his assistance is gratefully acknowledged.

This method does not take line stretch forces into account. They are considerably less than the extraction chute opening forces, and can usually be ignored. In the case of the ALBS test vehicle extraction, however, the line stretch "impulse" is believed to have led to the failure of test number 14 (see paragraph 4.15, main text). Thus, any future aerial extractions of the ALBS module will have to be planned with careful consideration given to the effect of this impulse on first stage component survivability.

The reader is asked to refer to paragraph 4.15, main text, where the normal load extraction sequence is described. The discussion which follows assumes that the ALBS 200-ft drogue extension line is fully extended and taut and that the unopened 28-ft ring-sail drogue chute has just been extracted, lines first, from its

1. Seaman, H. (1975) Deceleration System Trajectory Equations, AFFTC-TIM-75-5.

deployment bag. This is the starting point, t_o, of the buildup of deceleration forces, which reach a peak shortly before the extraction chute is fully open. (Figure 19, main text, shows the fully open extraction chute and the load just after being pulled off the ramp of the C-130.)

Before any calculations are made the basic equations involved will be presented and the rationale behind the program developed to assist in the calculations will be explained.

Note: The Seaman memorandum[1] covers compressibility effects and drag coefficient variations with speed. These effects are very pronounced as the speed approaches Mach 1. At the ALBS extraction speeds (0.32 M), however, these effects will be ignored in the calculations.

2. BASIC EQUATIONS

Note: The material in this section was obtained from AFFTC-TIM-75-5.[1]

2.1 Definition of Terms

T	Temperature, Absolute, Degrees Rankine (^oR)
T_o	Temperature, Absolute, at H = 0 (Standard = 518.688 ^oR)
P	Pressure, lb ft^{-2}
P_o	Pressure at H = 0 (Standard = 2116.216 lb ft^{-2})
ρ	Density, Atmospheric, lb sec^2 ft^{-4}
ρ_o	Density at H = 0 (Standard = 0.0023769 lb sec^2 ft^{-4})
g	Gravitational Constant = 32.17405 ft sec^{-2}
R	Gas Constant for Dry Air 1716.5 ft^2 sec^{-2} $^oR^{-1}$
a	Temperature Lapse Rate (Standard = 0.00356616 ^oR ft^{-1})
n	Dimensionless Exponent (Standard = 5.2561)
C_D	Dimensionless Drag Coefficient
S	Area ft^2
W	Weight lb
q	Dynamic Pressure lb ft^{-2}
D	Drag lb
V	Velocity ft sec^{-1}

V_x	Speed, Horizontal ft sec^{-1}
V_y	Speed, Vertical ft sec^{-1} (up is positive)
t	Time sec
H	Altitude ft
m	Mass $= \frac{W}{g}$
C_DS	Drag Area ft^2

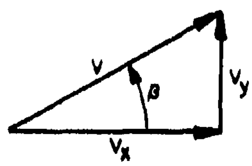
2.2 Derivation of Equations

2.2.1 BASIC EQUATION

Newton's second law of motion states that the acceleration of a body is proportional to the force exerted on the body, and inversely proportional to the mass of the body ($a = F/m$). The drag force (D) on an aerodynamic deceleration system is the product of dynamic pressure (q) and the drag area (C_DS) where

$$D = qC_DS \quad . \tag{A1}$$

The drag force is opposite in direction to the velocity and can be conveniently separated into orthogonal coordinates. The acceleration in the horizontal plane is $\Delta V_x/\Delta t$, and in the vertical plane is $(\Delta V_y/\Delta t + g)$. Using Newton's second law and Eq. (A1), and referencing the following diagram, the drag force can be expressed as:



VELOCITY VECTORS

$$D = qC_DS = -m\frac{\Delta V_x/\Delta t}{\cos\beta} = -m\frac{(\Delta V_y/\Delta t + g)}{\sin\beta} \quad . \tag{A2}$$

For the purposes of this memorandum, g (acceleration due to gravity at a point) is considered equivalent to G (gravitational constant). Mass can be expressed in terms of weight and the acceleration due to gravity:

$$m = \frac{W}{g} \quad . \tag{A3}$$

From the previous diagram:

$$\cos \beta = \frac{V_x}{V} \tag{A4}$$

$$\sin \beta = \frac{V_y}{V} \quad . \tag{A5}$$

Substituting (A3), (A4), and (A5) in (A2) and rearranging terms results in the basic trajectory equations:

$$\Delta V_x = - \frac{qC_D S g}{WV} V_x \Delta t \tag{A6}$$

$$\Delta V_y = - \frac{qC_D S g}{WV} V_y \Delta t - g \Delta t \quad . \tag{A7}$$

A step-by-step determination of distances and speeds can be calculated for sequential positions separated by time:

$$X_1 = X_0 + \Delta t \left(V_{x_0} + \frac{\Delta V_x}{2} \right) \tag{A8}$$

$$Y_1 = Y_0 + \Delta t \left(V_{y_0} + \frac{\Delta V_y}{2} \right) = H \tag{A9}$$

$$V_{x_1} = V_{x_0} + \Delta V_x \tag{A10}$$

$$V_{y_1} = V_{y_0} + \Delta V_y \quad . \tag{A11}$$

Note that the term gq/V appears in (A6) and (A7). The following are standard relationships:

$$q = \frac{1}{2} \rho V^2 \tag{A12}$$

$$\rho = \rho_0 \left(\frac{T_0 - aH}{T_0}\right)^{n-1} \qquad \text{ref 2} \tag{A13}$$

$$\rho_0 = \frac{P_0 n a}{g T_0} \quad . \qquad \text{ref 2} \tag{A14}$$

Substituting (A12), (A13), and (A14) into the common term gq/V results in:

$$\frac{gq}{V} = \frac{P_0 n a}{2 T_0^{\,n}} (T_0 - aH)^{n-1} V \quad . \tag{A15}$$

Set

$$K = \frac{P_0 n a}{2 T_0^{\,n}} \text{ (standard day K = 1.06556} \times 10^{-13}\text{)} \quad .$$

Then

$$\frac{gq}{V} = K(T_0 - aH)^{n-1} V \quad . \tag{A16}$$

Substituting (A16) in (A6) and (A7) results in:

$$\Delta V_x = - \frac{C_D S}{W} K(T_0 - aH)^{n-1} V V_x \Delta t \tag{A6a}$$

$$\Delta V_y = - \frac{C_D S}{W} K(T_0 - aH)^{n-1} V V_y \Delta t - g \Delta t \quad . \tag{A7a}$$

It is seen that for the general case, the terms $C_D S$, W, K, T_0, a, n, Δt, and g are constants. The variables are H, V_x, and V_y. These forms of the equations, with (A8), (A9), (A10), and (A11), lend themselves very well for use in programmable calculators. However, it should be noted that the use of (A13) limits these equations to altitudes below the stratosphere (H < 36089 ft). Also, the use of (A12) limits their use to incompressible flow.

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2. Standard Atmosphere – Tables and Data for Altitudes to 65, 800 ft (1955) National Advisory Committee for Aeronautics, Report No. 1235.

3. PROGRAM DEVELOPMENT

To develop a workable deceleration trajectory program for desk top or hand-held calculators one must resort to iterative techniques. Seaman's Eqs. (A8) through (A11) are ideally suited to this method of calculation, in that they generate successive new values of the variable parameters from a knowledge of the previous values and of the incremental changes in those values over a specified short time interval, Δt. The changes, of course, are derived from Eqs. (A6a) and (A7a).

Thus, if one knows the initial values of the three specified variables, V_{x_0}, V_{y_0}, and H_0, one can readily calculate (via appropriate programming) the values V_{x_1}, V_{y_1}, and H_1 for the moment when $t = t_0 + \Delta t$. The new values are then used in Eqs. (A6a) and (A7a) to develop the changes in horizontal and vertical velocity over a 2nd identical time interval. From these changes the program generates still another set of V_x, V_y and H values (V_{x_2}, V_{y_2}, H_2). This process is repeated until the parachute is fully open and peak extraction forces have been developed.

Thus far we have discussed only the three variables V_x, V_y, and H. Actually there are several more variables involved: q, V, ρ, S, x, and of course, D, the deceleration force which we are trying to determine.

Referring back to Eq. (A1) we see that $D = qC_DS$, that is, the deceleration force (drag) is the product of the dynamic pressure, q, and the effective drag area, C_DS. C_D is assumed constant here but S, the parachute area, is a function of the degree to which the chute has opened. The area, S, is assumed to increase linearly from a value of 0, when $t = t_0$, to a maximum value, S_0,* when $t = t_f$ (t_f = parachute opening time). It must be understood, therefore, that the value of the term S in Eqs. (A6a) and (A7a) is the instantaneous value, S_i, as determined by multiplying the term S_0 by the ratio of the elapsed time to the parachute opening time, that is, $S_i = S_0 \cdot t/t_f$.

The opening time, t_f, of the extraction chute is generally known from previous experience. (For the 28-ft ring slot chute, t_f is assumed to be about 0.7 sec). The elapsed time, t, is calculated by summing the time intervals since time zero. For example, if $\Delta t = 0.05$ sec, at the end of the 4th interval the elapsed time would be 4×0.05 or 0.2 sec, and the parachute would be 2/7ths open.

The other variable in Eq. (A1) is q, dynamic pressure, which, in turn, is a function of atmospheric density, ρ, and the square of the total velocity vector, V (see Eq. (A12)). Both ρ and V are variables. Changes in ρ are accounted for by assuming a standard atmosphere** and substituting newly generated values of H in

*The maximum parachute area is known as the reference area, S_0. This area is found from the equation $S_0 = \pi D_0^2/4$, where D_0 is the nominal diameter of the parachute.

**AFFTC-TIM-75-5 contains a method for relating actual or "test day" atmospheric conditions to the standard atmosphere, if so required.

Eq. (A6a) and (A7a) before each use. Changes in V are accounted for by finding the new values of V_x and V_y as explained above and using them to get a new value of V through the relationship: $V = \sqrt{V_x^2 + V_y^2}$. The new values of V so derived are used each time Eqs. (A6a) and (A7a) are solved.

Although "q" does not appear in Eqs. (A6a) and (A7a), it is customary to include dynamic pressure in the printout of the trajectory calculations so that the solution of Eq. (A1) is carried out by the program for each iteration. X, the horizontal distance traveled by the system, is solved by Eq. (A8) and the cumulative values of X are also printed out.

Figure A1 is a flow diagram of the program developed by the author to perform the trajectory computations on the calculators available to him.

4. FORCE CALCULATIONS

The aircraft velocity at time of release is established by the flight plan. This is taken as V, the total velocity, and, at release, $V_{x_o} = V$. $V_{y_o} = 0$ at this point. Altitude, H_o, is also known from the test plan. Thus, if we assume that the aircraft is at 25,000 ft, e.a.s. = 130 kt, we have established V_{x_o} at $130/\sqrt{0.4486} \times 1.689$ or 327.8 f/sec (99.92 m/sec), where ρ/ρ_o or σ for 25,000 ft = 0.4486.

With V_{x_o}, V_{y_o}, and H_o known, and with t_f and Δt established at 0.7 sec and 0.05 sec respectively, we can now use our program to calculate the deceleration forces involved for a 28-ft ring slot extraction chute. (C_D = 0.55.) The total system weight will be taken at 1520 lb. The results are printed below in Table A1. Note that the maximum force, 9813.74 lb, occurs when t = 0.6 sec.

Table A2 shows the forces generated by the 32-ft ring slot parachute with the same opening time and airspeed. The system weight and height have been changed to 1510 lb and 10,000 ft, respectively. It can be seen that the calculated deceleration force for the 32-ft chute is slightly higher than that for the 28-ft chute, despite the difference in altitude. Normally, the deceleration force decreases with a decrease in altitude. For example, the maximum force for the 28-ft chute at 10,000 ft all other conditions unchanged, is about 8700 lb.

Table A1. Trajectory Calculations, 28-ft Ring Slot Drogue Chute

t (s)	t/t_f	X (ft)	V_y(ft/s)	V_x(ft/s)	V (ft/s)	H (ft)	C_DS_i (ft^2)	q (psf)	F (lbf)	Remarks
.00	0	0	0	327.82	327.82	25,000	0	57.30	0	
.05	.0714	16.364	- 1.609	327.82	327.82	25,000	24.19	57.30	1386.07	D_o 28 ft
.10	.1429	32.599	- 3.203	326.35	326.36	24999.96	48.38	56.79	2747.48	
.15	.2143	48.664	- 4.769	323.45	323.48	24999.84	72.57	55.79	4048.50	C_D .55
.20	.2857	64.484	- 6.295	319.17	319.20	24999.64	96.76	54.33	5256.77	
.25	.3571	80.00	- 7.760	313.61	313.67	24999.30	120.95	52.46	6345.32	
.30	.4286	95.149	- 9.183	306.90	307.00	24999.01	145.14	50.25	7299.97	W 1520 lb
.35	.500	109.895	-10.528	299.19	299.33	24998.59	169.33	47.78	8090.94	
.40	.5714	124.197	-11.803	290.64	290.83	24998.10	193.52	45.10	8728.26	
.45	.6429	138.025	-13.004	281.42	281.67	24997.54	217.71	42.30	9210.30	t_f 0.7 s
.50	.7143	151.357	-14.130	271.69	272.00	24996.92	241.90	39.45	9543.54	
.55	.7857	164.181	-15.183	261.61	261.99	24996.24	266.09	36.60	9739.76	
.60	.8571	176.488	-16.167	251.33	251.79	24995.51	290.83	33.81	9813.74	V_1EAS 130 kt
.65	.9286	188.270	-17.083	240.97	241.51	24994.72	314.47	31.11	9781.82	
.70	1.0	199.557	-17.937	230.61	231.28	24993.89	338.66	28.53	9661.15	

Table A2. Trajectory Calculations, 32-ft Ring Slot Drogue Chute

t (s)	t/t_f	X (ft)	V_y(ft/s)	V_x(ft/s)	V (ft/s)	H (ft)	C_DS_i (ft^2)	q (psf)	D (lbf)	Remarks
.00	0	0	0	255.46	255.46	10,000	0	57.30	0	
.05	.0714	12.724	- 1.6087	255.46	255.46	10,000	31.60	57.30	1810.38	D_o 32 ft
.10	.14286	25.308	- 3.191	253.53	253.54	9999.96	63.19	56.44	3566.49	
.15	.2143	37.655	- 4.731	249.73	249.75	9999.84	94.79	54.77	5191.41	C_D .55
.20	.2857	49.689	- 6.204	244.21	244.26	9999.64	126.38	52.38	6620.43	
.25	.3571	61.319	- 7.595	237.16	237.25	9999.37	157.98	49.42	7807.44	
.30	.4286	72.551	- 8.895	228.86	228.98	9999.02	187.57	46.04	8727.84	W 1510 lb
.35	.500	83.280	-10.100	219.57	219.75	9998.61	221.17	42.40	9378.26	
.40	.5714	93.500	-11.208	209.60	209.84	9998.14	252.76	38.67	9773.25	
.45	.6429	103.196	-12.223	199.21	199.59	9997.60	284.36	34.96	9940.41	t_f 0.7 s
.50	.7143	112.366	-13.149	188.65	189.04	9997.02	315.95	31.38	9915.01	
.55	.7857	121.01	-13.995	178.12	178.60	9996.38	347.55	28.01	9735.15	V_1EAS 130 kt
.60	.8571	129.142	-14.769	167.78	168.47	9995.70	379.15	24.89	9438.00	
.65	.9286	136.801	-15.479	157.77	158.46	9994.99	410.24	22.05	9057.26	
.70	1.0	143.981	-16.134	148.17	148.98	9994.23	442.34	19.49	8621.89	

START

1. Enter .05 (Δt) in Reg. 02
2. Enter 518 688 (T_o) in Reg. 16
3. Enter 0035616 (a) in Reg. 17
4. Enter 32.174 (g) in Reg. 21
5. Enter 1 06556^{-13}(k) in Reg. 20
6. Enter 0011885 ($\frac{\rho_{msl}}{2}$) in Reg. 18
7. Enter 4.2561 (n-1) in Reg. 19
8. Enter 28 (D_o) in Reg. 00
9. Enter .55 (C_D) in Reg. 07
10. Xfer Reg. 02 to Reg. 08, divide by Reg. 04 ($\Delta t/t_f$).
11. RCL Reg 00 (D_o). Compute: $\left(S_o = \frac{\pi}{4} D_o^2\right)$
12. Multiply by Reg. 07 (C_D), Store $C_D S_o$ in Reg. 10.
13. SUBR 1000 (Compute σ).
14. Compute $(\sigma)^{-1/2}$, multiply by Reg 01 and by 1.689 $\left(V_{(fps)} = \frac{IAS(kt)}{\sqrt{\sigma}} \times 1.689\right)$ STORE in Reg. 01 & 12
15. Using contents of Reg. 15, 18 and 01 compute: $\left(q = .0011885\ \sigma\ V^2\right)$ STORE in Reg. 00
16. Enter 0 in Reg 05, 09, 11, 13 and 23

SUBR 1000

1. Using contents of Reg 17, 06 and 16, compute (T_o -aH) Store in Reg. 22, 15
2. Using contents of Reg. 15, 16, and 19 compute: $\sigma = \left(\frac{T_o - aH}{T_o}\right)^{n-1}$ Store in Reg. 15 (σ)

RETURN

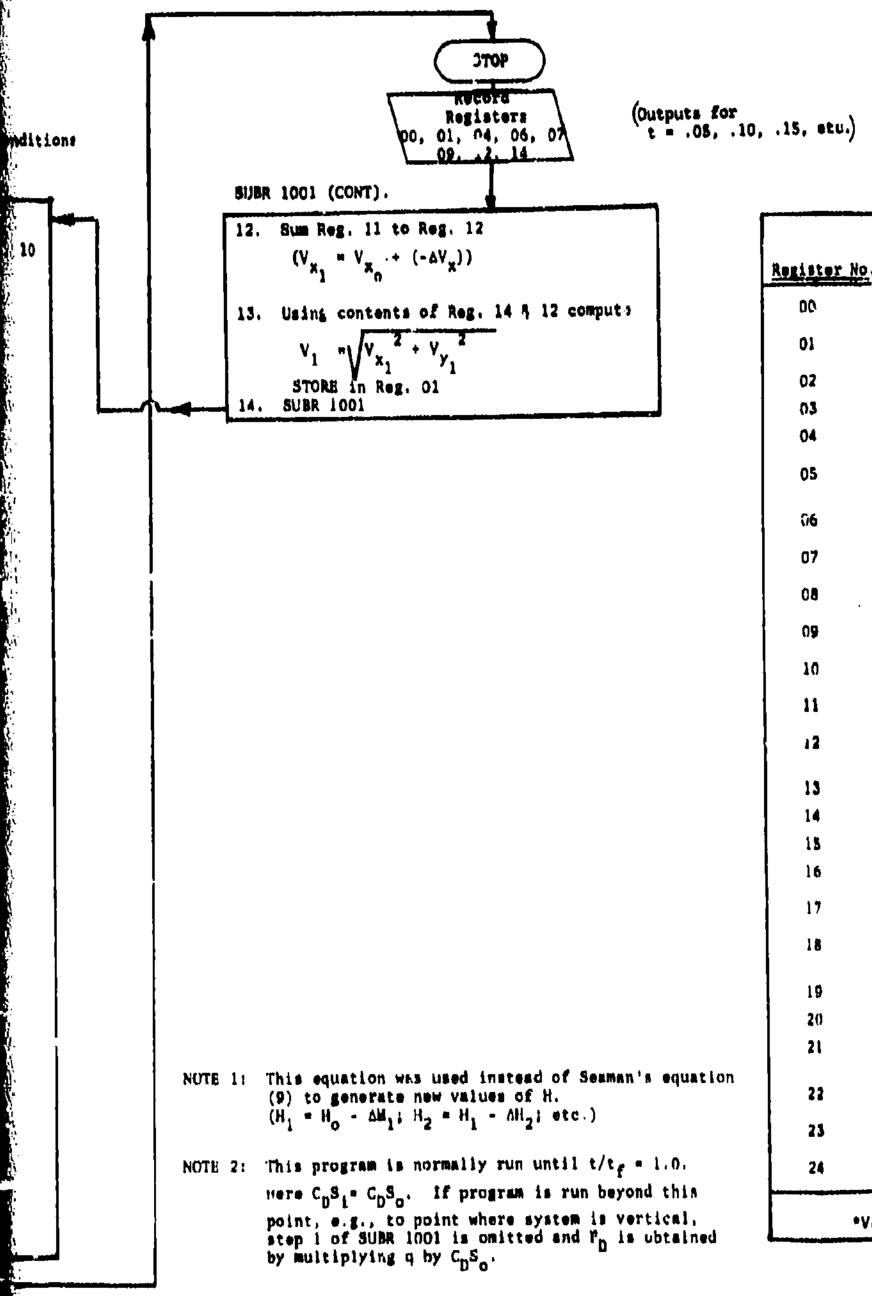
STOP

Record Registers 00, 01, 06, 12

(Initial conditions $t = t_o$)

SUBR 1001

1. SUM Reg 08 to Reg. 05, multiply by Reg. 10 $\left(C_D S_i = C_D S_o \times \frac{t}{t_f}\right)$ STORE in Reg. 07
2. Sum Reg. 13 to Reg. 06 ($H - \Delta H$)
3. SUBR 1000 (Compute σ)
4. Using contents of Reg. 15, 18, and 01 compute: $\left(q = .0011885\ \sigma\ V^2\right)$ STORE in Reg. 00
5. MULTIPLY by Reg. 07 $\left(F_D = q\ C_D S_i\right)$ STORE in Reg. 04
6. Using contents of Reg. 07, 03, 20, 22, 19, 01, & 02, compute (-B) $(-B) = -\left[\frac{C_D S_i}{W} + k(T_o - aH)^{n-1} + V_T \Delta t\right]$ STORE in Reg 15
7. Multiply (-B) by Reg. 12 $-\Delta V_x = (-B)V_x$ STORE in Reg. 11
8. Using contents of Reg. 15, 24, 21, 02, compute: $\left[-\Delta V_y = \left((-B)\ (-V_y)\right) - g\Delta t\right]$ STORE in Reg. 23
9. Using contents of Reg. 11, 12, 02, 09, compute: $X_1 = \left(X_o + \Delta t\left(V_{x_o} + \frac{\Delta V_x}{2}\right)\right)$ STORE in Reg. 09
10. Using contents of Reg. 23, 24, 02, compute: $-\Delta y = \Delta t\left[(-V_{y_o}) + \left(\frac{-\Delta V_y}{2}\right)\right] = -\Delta H$ STORE in Reg. 13 (SEE NOTE 1)
11. Using contents of Reg. 23 & 24 compute: $-V_{y_1} = \left((-V_{y_o}) + (-\Delta V_y)\right)$ STORE in Reg. 24 and 14



NOTE 1: This equation was used instead of Seaman's equation (9) to generate new values of H. ($H_1 = H_0 - \Delta H_1$; $H_2 = H_1 - \Delta H_2$; etc.)

NOTE 2: This program is normally run until $t/t_f = 1.0$. Here $C_DS_1 = C_DS_0$. If program is run beyond this point, e.g., to point where system is vertical, step 1 of SUBR 1001 is omitted and F_D is obtained by multiplying q by C_DS_0.

REGISTERS

Register No.	IN		OUT
00	28	D_0 (ft)	q
01	*	EAS(kt)	V_0, V_1, ..., (fps)
02	.05	Δt (s)	n/c
03	*	W (lb)	n/c
04	*	t_f (s)	F_{D_1}, F_{D_2}, ..., (lbf)
05	0		t/t_f
06	*	H_0 (ft)	H_1, H_2, ..., (ft)
07	.55	C_D	C_DS_1 (ft^2)
08	--		$\Delta t/t_f$
09	0		X_1, X_2, ... (ft)
10	--		C_DS_0 (ft^2)
11	0		$-\Delta V_x$ (fps)
12	V_{x_0}		V_{x_1}, V_{x_2}, ..., (fps)
13	0		$(-\Delta H)$ (ft)
14	--		WORKING
15	--		WORKING
16	578.688	T_0 (°R)	n/c
17	.0035616	a (°R/ft)	n/c
18	.0011885	$\frac{\rho_{msl}}{2}$ (slugs/ft^3)	n/c
19	4.2561	n-1	n/c
20	1.06556×10^{-13}	k	n/c
21	32.174	g (ft/s^2)	n/c
22	--		$(T_0 - aH)$ (°R)
23	0		$(-\Delta V_y)$ (fps)
24	0 (V_{y_0})		$(-V_{y_1})$ (fps)

*Variable manual input (all other inputs are entered by program)

Figure A1. Trajectory Program Flow Diagram

Appendix B

Determination of the Minimum Drag Force Needed to Allow the Drogue Chute to Extract the Packed Balloon from Its Container at the Apex of the Main Parachute

1. CONDITION*

The descending drogue and main chutes are both open and connected to each other by the 200-ft drogue extension line. The packed balloon rides at the apex of the main chute. The payload and simulated cryogenic unit are at the base of that chute. Extraction commences when the drogue is detached from the main chute and pulls on the balloon instead.

2. RATIONALE (SUMMARIZED FROM AFGL-TR-76-0196):[1]

(a) The total weight which the drogue must support at the end of the balloon extraction step (stage 3) is the sum of the weights of the drogue chute itself, the 200-ft extension line, the miscellaneous hardware attached to that line, the fully-extended balloon and its end fittings (items 1 through 4 on Figure C5, in Appendix C). (The remaining weight of the suspended system is borne by the main chute.)

(b) The minimum drag required of the drogue chute is equal to the total weight supported by it at the end of the extraction, plus a reasonable safety margin, for

*See paragraphs 3.2.3 and 3.2.5 main tex

1. Carten A.S. Jr. (1976) The Flight Test Aspects of the Air-Launched Balloon System Development Program, AFGL-TR-76-0196.

example, 60 lbf (267N). If the drogue cannot generate this minimum value of drag, it should not be used.

(c) Although the drag produced by the drogue chute is sharply degraded at the start of the balloon extraction (see Appendix C), it increases steadily as the balloon is pulled out of its container. The drag is at a maximum when the balloon is fully out and taut. At this point, the two parachutes (drogue and main, separated by the 200-ft drogue extension line and the 102-ft long balloon) are assumed to be acting as a single system. The actual drag of the drogue can then be computed on the following basis:

The maximum drag produced by the drogue equals the system drag at equilibrium velocity (see paragraph (e) and (f) below) times the ratio of the drogue drag area to the total system drag area, that is, to the sum of the drag areas of the main chute and the drogue chute.

(d) The resulting value of drag is the one selected to compare against the minimum drag requirement specified in paragraph (b) above. If too low, a new drogue chute must be selected. (See section B3 for actual calculations.)

(e) System drag, at equilibrium velocity, is equal to the total system weight.

(f) System equilibrium velocity (Ve_H) at a given altitude is determined from the formula:

$$Ve_H = \left[\frac{W}{\frac{\rho msl}{2} \cdot \sigma_H \cdot (C_D S_o)_{max}}\right]^{1/2}$$

where

W	= total system weight,
ρmsl	= sea level density,
	= 0.002378 slugs/ft^3 (1.225 kg/m^3),
σ_H	= density ratio for altitude H,
$(C_D S_o)_{max}$	= maximum system drag area or effective area (see paragraphs (h) and (i)).

(g) Dynamic pressure at altitude H, q_H, is determined from the equation:

$$q_H = \frac{\rho msl}{2} \cdot \sigma_H \cdot Ve_H^2 \quad .$$

(h) C_D (coefficient of drag) for a ring slot chute is taken as 0.55. For a ring sail chute, it is taken as 0.78. C_D for the system or "array" is calculated from the formula

$$C_{D_A} = \frac{(C_D S_o)_{Drogue} + (C_D S_o)_{Main}}{(S_o)_{Main} + (S_o)_{Drogue}} ,$$

(i) S_o = reference area of a parachute = $\frac{\pi D_o^2}{4}$

where

D_o = the nominal diameter of the chute.

3. CALCULATIONS

(a) Total weight supported by the 32-ft drogue (at the end of the balloon extraction) (see Section 2):

Item	Weight
32-ft (9.75-m) lightweight drogue	36 lb (160N)
200-ft (61-m) extension line	36 lb (160N)
misc. hardware	20 lb (89N)
balloon and end fittings	200 lb (890N)
Total Weight	292 lb (1299N)

(b) Minimum drag requirement: Let the "reasonable safety margin" be 60 lb (267N). Then, minimum drag requirement = 292 lb + 60 lb = 352 lb (1566N).

(c) Let the total system weight, as determined from weight measurements of the test vehicle components, be 1510 lb (6716.5N).

(d) Assume that the system (array) is at 9200 ft (2804 m) when the balloon extraction takes place (σ_H = 0.75732).

(e) Using a desk computer program based on the rationale expressed above, the following results (Table B1) were obtained for the 32-ft drogue/42-ft main chute combination. (See Table B2 for the 28-ft drogue/42-ft main chute combination.)

(f) Note that q in Table B1 is just within the upper limit of the range specified (0.5-1.0 psf, 23.94-47.88 N/m^2) and that the maximum drag of the drogue 438.57 lb (1951N) is well above the mininum value required (352 lb, 1566N), thus insuring a strong rapid extraction of the balloon.

(g) Table B2 shows corresponding values for the 28-ft ring slot drogue and 42-ft ring sail main chute combination. The system weight has been changed to 1520 lb (6761N) to allow for the increase in weight of the 28-ft parachute. The

Table B1. Area, Drag and Dynamic Pressure (q) Values for the 32-ft Ring Slot Drogue and 42-ft Ring Sail Main Chute Combination

Parachute	Type	Dia.	C_D	Reference Area (S_o)	Drag Area (C_DS_o)
Drogue	Ring Slot	32 ft 9.75 m	0.55	804.248 ft^2 74.72 m^2	442.336 ft^2 41.09 m^2
Main	Ring Slot	42 ft 12.8 m	0.78	1385.44 ft^2 128.71 m^2	1080.65 ft^2 100.4 m^2
Array	---	52.8 ft* 16.1 m	0.6955*	2189.69* ft^2 203.43 m^2	1522.98* ft^2 141.49 m^2

Drag of Drogue at Equilibrium Velocity	438.57 lb (1951 N)
Drag of Main Chute at Equilibrium Velocity	1071.43 lb (4766 N)
Total Drag at Equilibrium Velocity	1510 lb (6716.5 N)
Equilibrium Velocity (Ve_H)	33.18 fps (11.11 m/sec)
Dynamic Pressure (q)	.9916 psf (47.47 N/m^2)

*Theoretical, based on assumption that the two chutes behave as one composite chute.

minimum drag required of the drogue has also been increased by 10 lb (44.5N) to 362 lb (1610N). (Note that the calculated drag of the drogue is almost exactly equal to the required drag, while the calculated dynamic pressure falls slightly outside the specified range.)

Table B2. Area, Drag and q Values for the 28-ft Ring Slot Drogue Chute and 42-ft Ring Sail Main Chute Combination

System Weight = 1520 lb (6761 N) Altitude = 9200 ft (2804 N)

σ = .75732

Minimum Required Drag (Drogue) = 362 lb (1610 N)

Parachute	Type	Dia	C_D	Reference Area (S_o)	Drag Area (C_DS_o)
Drogue	Ring Slot	28 ft 8.52 m	0.55	615.752 ft^2 57.21 m^2	338.664 ft^2 31.46 m^2
Main	Ring Sail	42 ft 12.8 m	0.78	1385.442 ft^2 128.71 m^2	1080.645 ft^2 100.4 m^2
Array	---	50.48 ft* 15.39 m	0.709*	2001.19 ft^2 185.92 m^2	1419.309 ft^2 131.86 m^2

Dynamic Pressure, q, = 1.071 psf (51.28 N/m^2)

Equilibrium Velocity, Ve_H = 34.49 ft/sec (10.51 m/sec)

Drag of Drogue at Ve_H = 362.69 lb (1613.2 N)

Drag of Main Chute at Ve_H = 1157.31 lb (5147.7 N)

Drag of Array at Ve_H = 1520 lb (6761 N)

NOTE: The drag of the drogue and the drag of the main chute will remain constant, regardless of the altitude (0-25,000 ft) provided that the calculation is made at equilibrium velocity. Drag is a function of dynamic pressure and effective drag area. Under equilibrium conditions, both are essentially constant.

*Theoretical

Appendix C

Main Parachute Deployment and Balloon Extraction Calculations

1. INTRODUCTION

The report entitled "The Flight Test Aspects of the Air-Launched Balloon System (ALBS) Development Program"[1] contains calculations associated with the main parachute deployment and balloon extraction events, as initially conceived. However, the addendum to that report states that both the original parachute sizes and the distribution of weight on the main parachute were subsequently altered, invalidating some of the report's computational data. It further states that new, unpublished computations were carried out to predict the performance of the changed configuration. Those later computations, updated, are summarized now in this appendix, along with comparisons with actual test results.

In recomputing parachute performance data, the author became concerned about one heretofore neglected aspect of drogue parachute behavior, the phenomenon which he has called the "contracting spring problem." A fairly extensive mathematical treatment of the phenomenon was accomplished, in anticipation of possible adverse effects, and the calculations are summarized in this appendix.

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1. Carten, A.S., Jr. (1976) The Flight Test Aspects of the Air-Launched Balloon System Development Program, AFGL-TR-76-0196.

2. THE CONTRACTING SPRING PROBLEM, GENERAL CONSIDERATIONS

The contracting spring problem derives from the fact that the ALBS module, just prior to main chute deployment, is a large body or mass on the end of a long stretchable line the upper end of which is secured to the drogue chute. At main chute deployment, this body separates into two bodies, one of which is about three times as heavy as the other. The heavier body falls freely for a short time, while the lighter body – still attached to the long line – behaves as part of a typical spring-mass system; that is, it rises as the line recoils to its original unstretched length. As this happens, the drogue chute is drastically unloaded.

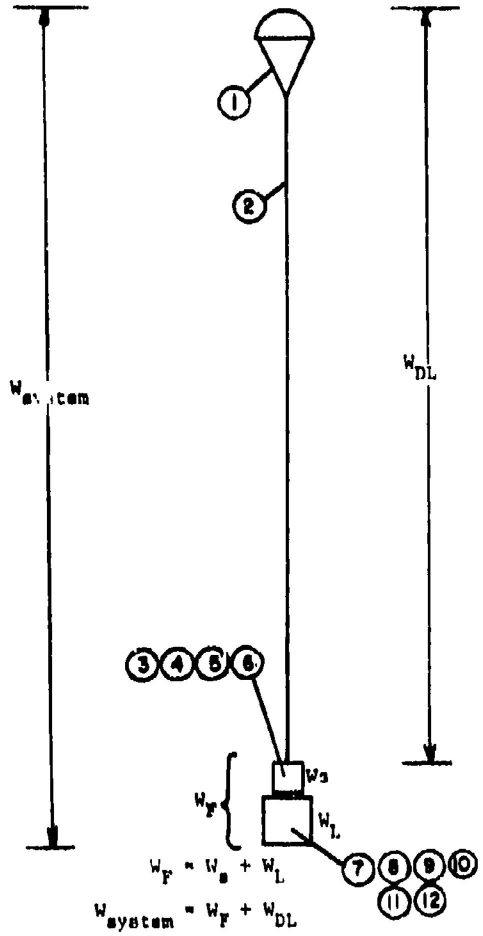
The author's initial concern was whether this unloading would collapse or destabilize the drogue chute, possibly preventing opening of the main chute. To answer this question, the duration of the unloading period had to be established. The discussion of section 3.2 is directed to determining that duration. Lt Gregory A. Vayda of the Aerospace Instrumentation Division assisted in the analysis of the problem[2] and his help is deeply appreciated. (As it turned out later, in actual flights, drogue chute stability was not degraded. The principal effect of the phenomenon was that the balloon containment bag (doughnut) was subjected to a much-larger-than-anticipated shock-force and had to be reinforced (see paragraph 3.3.3 and 4.7, main text).

3. MAIN CHUTE DEPLOYMENT EVENT 3a

3.1 Descriptive Model

Figure C1 depicts a model of the system just prior to main parachute deployment. At deployment, the W_L cluster of items starts to fall away from the W_s cluster. In reality this is the cryogenic unit and payload falling away from the packed balloon and the apex of the main 42-ft chute, dragging down with them both the suspension lines and the heavy centerline of the 42-ft chute. The free fall ends when the 51-ft centerline becomes taut. (This line is, by design, shorter than the suspension lines, allowing them to stay relaxed as an aid to rapid inflation of the main chute (see paragraph 3.4.3). When the main chute is fully deployed its inflation commences and is completed rapidly, leading to the configuration shown in Figure 9b in the main text.)

2. Vayda, G.A., 2/Lt, USAF (1976) Effect of Dropping a Mass From Stretched Parachute Cord, Air Launched Balloon System, unpublished AFGL technical memorandum.



System Components			
Item	Description	Wt(lbf)	Force (N)
1	28-ft drogue chute	46	204.6
2	200-ft line	36	160.1
3	misc. hardware on 200 ft line	20	89.0
4	Balloon & end fittings	200	889.6
5	balloon pack & linkage	20	89.0
6	3/4 main chute wt.	95	422.6
7	command/control pack	30	133.4
8	Ballast	0	0
9	Comm Relay (Dummy)	200	889.6
10	1/4 main chute wt.	30	133.4
11	Cryogenic Unit	753	3349.3
12	Recovery Chutes for Cryogenic unit	90	400.3
W_s	Sum of items 3,4,5,6	335	1490.1
W_L	Sum of items 7 - 12	1103	4906.1
W_F	Sum of W_s and W_L	1438	6396.2
W_{DL}	Sum of items 1 & 2	82	364.7
$W_{system} = W_F + W_{DL}$		1520	6761

Note: 1 pound force (lbf) = 4.448 Newtons (N)

Figure C1. Weight Distribution Sketch, Before Main Chute Deployment, Event 3a

3.2 Determination of the Drogue Chute Unloading Time

The values of system velocity and other parameters at the end of main chute deployment have to be calculated in order to establish deployment completion time, expected shock loading and initial conditions for main chute opening. (From these initial conditions, main chute opening time is predicted.) However, before the required parameters can be calculated, the time during which the drogue chute is unloaded must be determined by solving the contracting spring problem.

3.2.1 SYSTEM WEIGHT DISTRIBUTION

Referring to Figure C1, an overall system weight (W_{system}) of 1520 lb (6761N) is assumed.*,** Of this, 82 lb (364.7N) represent the combined weight, W_{DL},* of the drogue chute and the 200-ft (61 m) line; 1438 lb (6396.2N) represent the suspended ALBS test vehicle weight (W_F) prior to main chute deployment. (The stretch of the 200-ft line is due to the suspended 1438 lb).†

As main chute deployment is initiated, the large free-falling body W_L weighs 1103 lbs (4906.1N), while the smaller body, W_s, which is accelerating upwards, weighs 335 lb (1490.1N). (The box on Figure C1 identifies the items which make up the various weight combinations.)

3.2.2 BASIC FORMULAS AND CALCULATIONS

Note: The formulas and symbols stated below are essentially those used in the Vayda memorandum,[2] with some minor changes and additions. Table C1 lists the principal symbols used in the discussion. As each formula is introduced, a calculation is performed using that formula and the weights listed on Figure C1.

Eq. (1) $x = 0.0118\ F_k + 4.9012$

This is an empirical equation for stretch distance developed from a loading curve for 2 in 1 Nylon over the loading range involved in our problem. The 200-ft

---

*Weight is treated as a force and the English units of measurement, lb, are understood to represent units of pound-force (lbf). The corresponding metric unit is the Newton (N). (1 lbf = 4.448N).

**The 1520 lb system weight is typical of the weights actually measured during the flight tests at the NPTR in which a 28-ft ring slot drogue chute was used. Computations made prior to the start of the NPTR flights used a system gross weight of 1383 lb (6152N), a weight which had to be revised upward as experience was gained. The increase was due to added hardware and rigging. (The ALBS module which was to be dropped in the Holloman AFB test weighed approximately 1770 lbs, reflecting a further growth in system size and complexity, especially in the cryogenic unit interface.)

†The drogue chute is treated here as a stationary beam. All velocities are relative to a fixed system and ignore the fact that the parachute system is actually descending through the atmosphere.

Table C1. Table of Symbols

a'	=	Maximum theoretical distance above no-tension point
F	=	net force on system
F_k	=	force on spring, = W_F when t = o, that is at release
F_m	=	force on attached mass, = $-W_s$, when t = o
k	=	spring constant
m	=	mass of smaller body = $\frac{W_s}{Ay}$
x	=	distance parachute cord is stretched
x'	=	spring length (distance small body travels upward in returning to no-tension point) ($x' = x$)
A_y	=	acceleration due to gravity (32.2 ft/sec^2)
v	=	velocity, velocity at no-tension point
y	=	vertical height; actual distance above no-tension point
t	=	elapsed time; time to no-tension point
t'	=	time from no-tension to a'
t''	=	time from no-tension to y
W_F	=	weight of the suspended body before separation
W_s	=	weight of the small body, after separation
W_L	=	weight of the larger body, after separation

(61 m) line was assumed to have the same stretch characteristics. (Later information suggested that the 200-ft line, which was constructed of 2 ply Type 23, 12,000 lb (5.34×10^4 N) breaking-strength Nylon webbing may actually have less stretch under load, but no definitive value was obtained).

Thus, when F_k = 1438 lbs, x = 21.87 (6.67 m)

Eq. (2) $k = F_k/x$.

This equation for the spring constant can be rearranged to read:

Eq. (2a) $F_k = kx$. (This relationship will be used later, in developing Eq. (10).)

Using Eq. (2), we see that the spring constant k = 65.752 lb/ft (959.6 N/m).

To obtain the mass of the smaller body we use, Eq. (3) $m = F_m/Ay$.

Thus, if the smaller body weighs 335 lb, (1490.1N) it has a mass of 335/32.2 or 10.404 slugs (151.83 kg).

In our spring-mass system, the mass being accelerated upward will rise to the point of no tension, that is, to the point where the stretch in the spring (200-ft line) has been reduced to zero. The mass will still have velocity at that point, however, and will continue to rise until the residual velocity is cancelled out by gravitational forces or by some other constraint. The 200-ft line is then slack and the mass will fall until that line becomes taut once more.

During the initial upward acceleration of the small body, the force of that body (F_m) will act on the drogue, until the no-tension point is reached. Then, during the time it takes the small body to rise to its maximum distance above the point of no-tension and to descend back to that point, force F_m is removed from the drogue. In essence, the drogue "sees" only its own weight and that of the empty 200-ft line. (Force is reapplied to the drogue when the 200-ft line becomes taut again.)

We shall now calculate the times, distances, and velocities involved in the rise to no-tension, to maximum height above no-tension and to return to no-tension.

For our spring-mass system, the following basic equations for velocity, force on the smaller body, and net force are used to derive the equations actually employed in our calculations:

Eq. (4) $v = -1/k \cdot dF_k/dt$.

Eq. (5) $F_m = m\ dv/dt$.

Eq. (6) $F = F_k - F_m$.

(a) Rearranging Eq. (4)

$$dF_k = -kv\ dt$$

and integrating, we get

$$F_k = -kvt + C\ .$$

(b) When $t = 0$, $F_k = W_F$ = weight of the suspended body before separation = 1438 lb in our example (see Figure C1). Thus, $C = 1438$ and

Eq. (7) $F_k = -kvt + 1438$.

(c) Substituting Eqs. (7) and (5) into (6)

$$F = 1438 - kvt - m\,dv/dt$$

$$Fdt = 1438\,dt - kvt\,dt - m\,dv \text{ (after multiplying through by dt)}$$

$$m\,dv = 1438\,dt - kvt\,dt - Fdt \text{ (after rearranging terms)}$$

$$dv = 1/m\,(1438\,dt - kvt\,dt - Fdt) \text{ (after dividing through by m)}$$

$$v = 1/m\,(1438\,t - 1/2\,kvt^2 - Ft) + C \text{ (after integrating both sides)}$$

or,

Eq. (8) $v = (1438 - 1/2\,kvt - F)\,t/m + C$ (after factoring out t)

where v is the velocity of the upward-moving body.

(d) At release, that is, when t = o, the upward velocity, v, is o, and the constant C in Eq. (8) becomes 0, whence

Eq. (9) $v = (1438 - 1/2\,kvt - F)\,t/m.$

(e) Stated in more general terms:

$$v = \left(F_k - \frac{kvt}{2} - F\right)\frac{t}{m} \qquad \text{where } 1438 = F_k \text{ when } t = o$$

or,

$$v = \left(F_k - \frac{kxt}{2t} - F\right)\frac{t}{m} \qquad \text{where } v = \frac{x}{t}$$

or,

$$v = \left(F_k - \frac{F_k}{2} - F\right)\frac{t}{m} \qquad \text{where } F_k = kx \text{ (Eq. 2a)}$$

whence,

Eq. (10) $$v = \left(\frac{F_k}{2} - F\right)\frac{t}{m}.$$

(f) If we let the spring length, x', be equal to the stretch distance, x, which is the case at the no-tension point, and if we substitute x'/t for v in Eq. (10): we get

$$\frac{x'}{t} = \left[\frac{F_k}{2} - F\right]\frac{t}{m}$$

or,

Eq. (11) $x' = \left[\frac{F_k}{2} - F\right]\frac{t^2}{m}$.

(g) To determine the time required for the spring (200-ft line) to contract so that there is no tension on it, we rearrange Eq. (11) as follows:

Eq. (12) $t = \left[\frac{mx'}{\frac{F_k}{2} - F}\right]^{1/2}$.

We are now ready to calculate t, the time to the no-tension point. We use Eq. (12), and let $F = -F_m$, because at the no-tension point the only force is that on the ascending small body. (F_k, the force on the spring = 0 at this point, and $F = F_k - F_m$ per Eq. (6).) The values of m, x' and F_k are as previously stated:

$$t = \left[\frac{10.404 \text{ slugs} \times 21.87 \text{ ft}}{\frac{1438 \text{ lb}}{2} - (-335 \text{ lb})}\right]^{1/2} = 0.4646 \text{ sec}$$

using this value of t in Eq. (10), we solve for the velocity of the small body at no tension:

$$v = \left[\frac{F_k}{2} - F\right]\frac{t}{m} = \left[\frac{1438}{2} - (-335)\right]\frac{0.4646}{10.404} = 47.067 \text{ fps } (14.346 \text{ m/sec}) .$$

If there were no other restraints on the upward moving small body, it would rise to a theoretical maximum height above the no-tension point. Actually there is a restraint, as will be discussed shortly, which keeps the body from rising that high. The methods for determining the theoretical maximum height will be presented nevertheless because they are relevant later in the discussion of the balloon extraction process (see Section 4).

(a) To obtain the maximum theoretical distance (a') above no-tension we must first determine the time, t', required to reach that point.

$v_f = v - Ayt'$ where v_f final velocity at a' = o

or

$o = v - Ayt'$

whence,

Eq. (13) $t' = \frac{v}{A_y}$

or

$$t' = \frac{47.067 \text{ fps}}{32.2 \text{ f/sec}^2} = 1.4617 \text{ sec} \quad .$$

(b) The theoretical maximum distance above no tension, a', is determined next:

$$a' = y_o + \frac{1}{2}(V_o + V_f)\, t'$$

or

Eq. (14) $a' = \frac{v}{2} \times t'$ where $V_o = v$ and $V_f = o$

whence

$$a' = \frac{1}{2}(47.067)(1.4617)$$

$$= 34.40 \text{ ft } (10.49 \text{ m}).$$

(c) The elapsed time from release of the suspended weight to maximum theoretical height (a') of the small body is the sum of t and t'. In our case, it is 0.4646 + 1.4617 or 1.926 sec.

3.2.3 EFFECT OF THE MAIN CHUTE CENTERLINE

Up to this point we have considered only an unrestrained spring-mass system. However, as previously mentioned, there is actually a restraint which limits the travel of the small body above the no-tension point. This restraint is, of course, the 51-ft long centerline of the 42-ft diameter main chute.

The two bodies into which the suspended body (F_k) separates at main chute deployment act independently of each other while the centerline is slack. One falls freely, the other is accelerated upward. When the centerline becomes taut again, an exchange of momentum between the two bodies occurs so that there is in effect a single mass moving downward at a speed less than that of a free-falling body. This exchange happens before the ascending smaller body can reach the theoretical maximum height above no tension. To find the time, t'', at which the exchange of momentum occurs the following calculations are performed:

Note that t, the time from release to the no-tension point, is a vital point of reference in these calculations. This is so because at t the two oppositely moving bodies are subjected to the same constant acceleration force, Ay.

(a) First we find the velocity of the larger falling body (V_{yL}) at 0.4646 sec, which is the time to no tension, t.

$$V_{yL} = V_{yL_o} + Ay\,t \quad , \quad \text{where} \quad V_{yL_o} = 0$$

or,

Eq. (15) $V_{yL} = Ayt$

whence

$V_{yL} = -32.2\ (0.4646)$

$V_{yL} = -14.96$ ft/sec (-4.56 m/sec) .

(b) The distance from the separation point which the large body has fallen, y_L, is determined as follows:

$$y_L = y_{oL} + \frac{1}{2}\,(V_{yL_o} + V_{yL})\,t \quad , \quad \text{where} \quad y_{oL} \text{ and } V_{yL_o} = 0$$

or,

Eq. (16) $y_L = \dfrac{V_{yL}}{2} \cdot t$

whence

$y_L = \frac{1}{2}\ (-14.96)(0.4646)$

or

$y_L = -3.475$ ft. (-1.0592 m) .

(c) The initial separation velocity, Vso, at t = 0.4646 sec, is determined from the formula:

Eq. (17) $V_{so} = V_{yL} - v$

whence

$$V_{so} = -14.96 - 47.067$$

or

$$V_{so} = -62.03 \text{ ft/sec } (-18.91 \text{ m/sec}) .$$

(d) The initial separation distance at t, y_{so}, is obtained from

Eq. (18) $$y_{so} = y_L - x$$

$$y_{so} = -3.475 \text{ ft} - 21.87 \text{ ft}$$

$$= -25.345 \text{ ft } (-7.725 \text{ m}) .$$

(e) We know that the maximum separation, y_c, between the two bodies is set at 51 ft (15.55 m) by the length of the centerline. Thus, we can find the final separation velocity, Vs, as follows:

$$V_s^2 = V_{so}^2 + 2 A_y (y_c - y_{so})$$

or

Eq. (19) $$V_s = \sqrt{V_{so}^2 + 2 A_y (y_c - y_{so})}$$

whence

$$V_s = [(-62.03)^2 - (64.4)(-51 + 25.35)]^{1/2}$$

or

$$V_s = -74.16 \text{ ft/sec } (-22.6 \text{ m/sec}) .$$

(f) We now must find the time, t'', between the no-tension point and the maximum separation of 51 ft.

$$V_s = V_{so} + A_y t''$$

or

Eq. (20) $$t'' = \frac{V_s - V_{so}}{Ay}$$

whence

$$t'' = \frac{-74.16 + 62.03}{-32.2}$$

or

$t'' = 0.3767$ sec.

(g) To determine the maximum distance the small body goes above the no-tension point, we must first find the final velocity of the body at maximum distance above no-tension point.

Eq. (21) $V_{ys} = v + A_y t''$

$$V_{ys} = 47.07 - (32.2)(.3767)$$

$$V_{ys} = 34.939 \text{ ft/sec } (10.65 \text{ m/sec}) .$$

(h) Now the distance above no-tension point can be found.

Eq. (22) $y = y_o + \frac{1}{2}(V_{ys} + V)\, t''$ Let $y_o = o$

$$y = \frac{1}{2}(34.94 + 47.07)(0.3767)$$

$$y = 15.45 \text{ ft } (4.71 \text{ m})$$

If we sum the time required to reach the no-tension point (0.4646 sec) to the additional time required to reach the maximum separation distance (0.3767 sec), we obtain the total time ($t + t''$) (0.8413 sec) required for the system to go from the release point to the point where the centerline becomes taut (maximum separation distance).

At time t'', the upward motion of the smaller body is stopped by the sudden application of the force of the larger free-falling body. The smaller body starts downward under this force until the slack in the 200-ft line is removed. The total force on both bodies is then transmitted up the 200-ft line to the drogue chute which becomes fully loaded once more.

The exchange of momentum between the large and small bodies, when the centerline of the main chute becomes taut, is expressed by the formula:

$$v_F m_F = m_L v_L + m_s v_s$$

or

Eq. (23) $v_F = \dfrac{m_L v_L + m_s v_s}{m_F}$

where

L refers to the large body

s refers to the small body

F refers to the final or combined body

m = mass

v = velocity

This can also be written as

Eq. (24) $$v_{F'} = \frac{-W_L(t + t'') + m_s v_{ys}}{W_F/Ay}$$

where

$$m_L v_L = -\frac{W_L}{Ay} \cdot (t + t'')\, Ay$$

and

$$v_s = v_{ys}$$

whence

$$v_F = \frac{-(1103)(0.8413) + (10.404)(34.939)}{(1438/32.2)} = -12.639 \text{ fps } (-3.85 \text{ m/sec}) .$$

Knowing $v_{F'}$, the resultant downward velocity, and y, the actual maximum distance above no tension, we can compute t''', the time it takes for the slack to be removed from the 200-ft line. This is a free-fall situation again, with an initial velocity equal to $v_{F'}$.

Let v_T = the terminal velocity of the falling body when the line slack is used up. Using the form of Eq. (19):

Eq. (25) $$v_T^2 = V_F^2 + 2Ay\,(y_T - y_y)$$

where

$$y_T = o$$

and

$(y_T - y_y)$ = -y or minus the maximum distance above no tension. This is the distance which must be travelled downward before 200-ft line becomes taut again.

whence

$$v_T = \sqrt{(-12.639)^2 + (-64.4)(-15.45)}$$
$$= -33.981 \text{ fps } (-10.36 \text{ m/sec})$$

The time (t''') to traverse this distance is found by dividing the distance by the average velocity, or

$$\text{Eq. (26)} \quad t''' = \frac{-y}{\frac{(-v_F) + (-v_T)}{2}} = \frac{-15.45}{\frac{(-12.639) + (-33.981)}{2}} = 0.6628 \text{ sec}$$

3.2.4 TIME SUMMATION

From all these computations we see that the total no-tension time (t'' + t''') is 0.3767 sec + 0.6628 sec or 1.0395 sec. Also, the time from release to the reapplication of full load to the drogue chute is the sum of times t, t'' and t''' or 0.4646 sec + 1.0395 sec or 1.5041 sec. Table C2 summarizes the foregoing computations.

The author developed a calculator program (P-20) which solves the contracting spring equations described above and provides the outputs listed on Table C2.

3.3 Main Chute Deployment Calculations

3.3.1 COMPUTATIONAL METHOD

In the contracting-spring model discussions, we treated the system as fixed, that is, we ignored the fact that it was descending through the atmosphere. We must now return to the real world in order to complete our main chute deployment calculations. The main computational tool will be the author's program P-13A, which is described in an earlier report.[1]

Figure C2 summarizes the results of the computation carried out for a 1520 lb system, using the times just obtained in solving the contracting spring problem. The initial system velocity (-89.82 fps, -27.38 mps) is the equilibrium velocity for such a system when supported by the 28-ft ring slot drogue chute at an altitude of 23,800 ft (7254 m), the estimated system altitude 10 sec after release.

The drag on the 28-ft drogue chute at equilibrium is approximately the system weight, 1520 lb. When the 42-ft main chute is deployed the load on the drogue is drastically reduced from full system weight to 417 lb (1855N). (Referring back to Figure C1, the 417 lb is the sum of weights W_s and W_{DL}.) The drogue is assumed to maintain this loading until time t, the time to no-tension (0.4646 sec), as just determined (paragraph 3.2.2).

Table C2. ALBS Contracting Spring Data Summary for Main Chute Deployment, Event 3a

Symbol	Parameter	English Units	Metric Units
F_k or W_f	Total suspended wt. less drogue and line	1438 lbf	6396.2 N
$-F_m$ or $-W_s$	Residual wt after release of W_L	-335 lbf	-1490.1 N
Ay	Gravitational constant	32.2 ft/sec^2	9.81 m/sec^2
y_c	Specified separation distance	-51 ft	-15.54 m
M_s or m	Small mass (-Ws/Ay)	10.404 slugs	151.83 kg
x	Stretch distance (.0118 F_k + 4.9012)	21.87 ft	6.67 m
k	Spring constant F_k/x	65.753 lb/ft	959.6 N/m
t	Time to no-tension point (n.t.)	.4646 sec	.4646 sec
$-v_{so}$	Initial separation velocity, at time t	-62.03 f/sec	-18.91 m/sec
v	Velocity of small mass, at time t	47.067 f/sec	14.346 m/sec
$-v_{y(L)}$	Velocity of large mass, at time t	-14.96 f/sec	4.56 m/sec
$-y_L$	Free fall distance, at time t	-3.475 ft	-1.0592 m
$-y_{so}$	Initial separation distance ($-y_L$-x), at time t	-25.345 ft	-7.725 m
a'	Theoretical max. distance above n.t.	34.40 ft	10.49 m
t'	Time to a' (theoretical)	1.4617 sec	1.4617 sec
t + t'	Time from release to a' (theoretical)	1.926 sec	1.926 sec
y	Max. actual distance above n.t.	15.45 ft	4.71 m
v_{ys}	Velocity of small mass at y	34.939 fps	10.65 m/sec
$-v_{so_f}$	Final sep. velocity, at y (Vs)	-74.18 fps	-22.6 m/sec
t''	Time from no tension to y	.3767 sec	.3767 sec
t + t''	Time from release to y	.8413 sec	.8413 sec
$-v_F$	Velocity of combined mass at t + t''	-12.639 fps	-3.85 m/sec
t'''	Time to eliminate line slack	.6628 sec	.6628 sec
v_T	Terminal velocity of combined mass	-33.981 fps	-10.36 m/sec
t'' + t'''	Total no tension time	1.0395 sec	1.0395 sec
t + t'' + t'''	Time to reapply full load	1.5041 sec	1.5041 sec

Date: 8/14/77

Contracting Spring Data

(from P-20):

t = .4646s - time to no tension

t'' = .3767s - time to Y

t''' = .6628s - time to no slack

t'' + t''' 1.039s (total no tension time)

t + (t'' + t''') - time to reapply full load 1.5041s

Subject: Event 3a

28' Drogue chute (r.slot)
42' Main chute (r. sail)

Program P13A

ALBS MAIN PARACHUTE
DEPLOYMENT COMPUTATION

t(sec)	psf q	fps Δv	fps -v	lb D	ft H	lb W	fps Ve	ΣΔH
0	4.490	-	-89.82	1520	23800	417	-	0
.05	4.07	3.714	-86.11	1378.82	"795.6		47.047	- 4.40
.10	3.76	3.306	-82.80	1273.36	"791.4		" .043	- 8.62
.15	3.49	2.96	-79.84	1183.0	"787.3		" .040	-12.69
.20	3.26	2.66	-77.19	1104.99	"783.4		" .036	-16.61
.30	2.89	2.17	-72.63	977.91	"775.9		" .030	-24.10
.40	2.598	1.79	-68.88	879.77	"768.8		" .024	-31.17
.45	2.48	1.63	-67.25	838.93	"765.4		" .021	-34.57
.50	2.183	12.907	-54.34	739.43	"762.4	82	20.849	-37.61
.55	1.45	8.021	-46.32	490.51	"759.9		"	-40.13
.60	1.07	5.49	-40.83	361.48	"757.7		" .848	-42.31
.65	.840	3.98	-36.85	284.53	"755.8		" .847	-44.25
.70	.692	2.99	-33.86	234.51	"754.0		" .846	-46.01
.80	.517	1.83	-29.71	175.23	"750.82		" .845	-49.18
.90	.422	1.19	-27.05	142.76	"748.0		" .844	-52.01
1.00	.364	.809	-25.26	123.20	"745.4		"	-54.62
1.25	.293	.338	-22.82	99.20	"739.4		" .840	-60.59
1.45	.269	.177	-21.90	91.01	"734.9		" .839	-65.05
1.50	.459	-1.45	-23.346	155.36	"733.8	1520	89.719	-66.19
1.55	.501	-1.43	-24.78	169.77	"732.6		" .717	-67.40
1.60	.545	-1.41	-26.19	184.67	"731.33		" .715	-68.66
1.80	.734	-1.35	-31.64	[illegible]	"725.5		" .706	-74.45
2.00	.939	-1.27	-36.89	317.94	"718.7		" .696	-81.31

LEGEND

D	Drag force
W_s	System Weight 1520 lb
D_o	Chute nominal dia. 28 ft
v_i	initial(release)velocity
v	instantaneous velocity
Δv	Change in velocity
$t_f/50$	calculation interval (s)
t	actual time (s)
ΣΔH	summation of height changes
W_i	initial weight (chute + load)
W	instantaneous weight
q	dynamic pressure
ρ	atm. density
H_i	release altitude
H	instantaneous altitude
σ	density ratio ρ/ρo
W_B	Weight of ALBS balloon
W_{OT}	" other components suspended on drogue
C_D	coeff. drag (chute) .55
S_O	Ref. Area of chute
Ve	Projected Equilibrium Velocity for system of Weight, W

Registers	00	01	02	03	04	05	06	07	08	09	10	11	12	13
IN	-	$-v_i$ -89.82	$t_f/50$ .05	W_i .417	ρ_{H} MSL .001189	-	H_i 23900	$\rho_{H-1000'}$ .48442	σ_H .46787	$W_B/0$ -	$(C_D S_O)_{max}$ 338.663	Count No.50	0	$W_{OT}/-\Delta H$ 0
OUT	q	$-v_{1,2}$	-	W	-	-	$H_{1,2,3}$	D	-	-ΣΔH		-	$V_e/-v$	-ΔH

Figure C2. ALBS Main Chute Deployment, Event 3a, Computations 1520 lb

At the no-tension point the drogue is assumed to experience only the loading associated with its own weight and that of the 200-ft line, W_{DL}, or 82 lb (365N). It stays in this lightly-loaded condition until time t + (t'' + t'''), that is, until the slack in the 200-ft line is taken up. It then sees the whole system load again.

The data summary on Figure C2 tracks dynamic pressure, velocity, velocity change, drag, height, and height change as the system descends. Calculations are performed at 0.05 sec intervals and are carried out from the start of deployment until 0.5 sec after the 200-ft line becomes taut again. The actual opening of the main chute is assumed to commence at this point, an assumption which proved to be in good agreement with actual flight test experience (see 3.4.1).

3.3.2 DYNAMIC PRESSURE VARIATIONS

The dynamic pressure (q) track on Figure C2 is of particular interest. If the value of q falls off too greatly, the danger of drogue chute collapse is strong, according to parachute literature. A dynamic pressure less than 0.3 lb/ft^2 (14.36 N/M^2) is considered cause for concern. The calculated q values on Figure C2 do fall slightly below that figure just before the full load is reapplied to the drogue chute. However, in the actual flight tests, no drogue chute instability at this point was observed. Thus, if the calculations are accurate, it would appear that this type of ring slot parachute, with its high geometric porosity, is not particularly sensitive to the 0.3 lb/ft^2 dynamic pressure threshold.

Figure C3 was generated in the same manner as Figure C2 using a system gross weight of 1383 lb (6152N) and a 32-ft-diam (9.18 m) drogue chute. It represents the ALBS configuration at the start of the test program and is offered for comparison purposes.

3.3.3 DEPLOYMENT SHOCK FORCES

The velocities generated in the contracting spring problem solution suggest that fairly strong deceleration shocks will be experienced during the main chute deployment, particularly during the exchange of momentum between the two bodies W_L and W_s, as described in paragraph 3.2.3.

If we allow the deceleration force, F_D, to be the force on the larger body W_L, then

$$F_D = \frac{W_L}{Ay} \cdot \frac{\Delta v}{\Delta t}$$

where

$\frac{W_L}{Ay}$ = mass of the larger body

Date: 1/18/77

Contracting Spring Data

(from P-20):

t = .45s - time to no tension

t'' = .38s - time to Y

t''' = .65s - time to no slack

t'' + t''' 1.03s(total no tension time)

t + (t'' + t''') - time to reapply full load 1.48s

Subject: Event 3a

32' Drogue chute (r. slot)
42' Main chute (r. sail)

Program P13A

ALBS MAIN PARACHUTE DEPLOYMENT COMPUTATION

t(sec)	psf q	fps Δv	fps -v	lb D	ft H	lb W	fps Ve	ΣΔH
0	3.09	-	-75.0	-	23930	366	"	-
.05	2.82	+3.879	-71.12	1247.76	"926.3		38.654	- 3.65
.10	2.55	-	-67.76	1128.80	-		" .651	-
.15	2.33	-	-64.84	1030.70	-		" .649	-
.20	-	-	-62.28	-	-		" .646	-
.30	-	-	-58.01	-	-		-	-
.40	1.645	-	-54.64	737.55	-		" .636	-25.25
.45	1.559	+1.42	-53.22	689.88	23902.1		" .635	-27.95
.50	1.364	+11.86	-41.33	603.54	"899.7	72	17.136	-30.31
.55	.8395	+6.694	-34.64	371.35	"897.8		" .135	-32.21
.60	.5997	-	-30.32	265.27	-		" .134	-
.65	.4663	+3.002	-27.31	206.24	"894.7		.133	-35.28
.70	.3834	-	-25.13	-	-		"	-
.80	.2898	+1.256	-22.24	128.17	"891.05		"	-38.95
.90	.2410	-	-20.49	106.61	-		" .132	-41.08
1.00	.2129	-	-19.37	96.19	"886.93		" .131	-43.06
1.25	.1809	+ .1790	-17.98	80.00	"882.28		" .130	-47.71
1.50	.1697	+ .0685	-17.46	75.06	"877.9		17.129	-52.13
1.55	.299	-1.456	-18.92	132.34	"876.96	1383	75.07	-53.04
1.60	.3339	-1.438	-20.35	147.70	"876.0		"	-54.02
1.80	.4863	-	-25.91	215.14	-		" .062	-58.65
2.00	.6561	-1.271	-31.136	290.25	" 865.63		" .055	-64.37

LEGEND

D	Drag force
W_s	System Weight 1383 lb
D_o	Chute nominal dia. 32 ft
v_i	initial(release)velocity
v	instantaneous velocity
Δv	Change in velocity
$t_f/50$	calculation interval (s)
t	actual time (s)
ΣΔH	summation of height changes
W_i	initial weight (chute + load)
W	instantaneous weight
q	dynamic pressure
ρ	atm. density
H_i	release altitude
H	instantaneous altitude
σ	density ratio ρ/ρo
W_B	Weight of ALBS balloon
W_{OT}	" other components suspended on drogue
C_D	coeff. drag (chute) .55
S_O	Ref. Area of chute
Ve	Projected Equilibrium Velocity for system of Weight, W

Registers	00	01	02	03	04	05	06	07	08	09	10	11	12	13
IN	-	$-v_i$ -75	$t_f/50$ .05	W_i 366	½ MSL .001189	-	H_i 23930	$\sigma_{H-1000'}$ .48225	σ_H .46576	$W_B/0$ -	$(C_D S_O)_{max}$ 442.34	Count No.50	0	$W_{OT}/-\Delta H$ 0
OUT	q	$-v_{1,2}$	-	W	-	-	$H_{1,2,3}$	D	-	-ΣΔH	-	-	$V_e/-v$	-ΔH

Figure C3. ALBS Main Chute Deployment, Event 3a, Computations 1383 lb and

$$\frac{\Delta v}{\Delta t} = \text{deceleration}$$

or

Eq. (27) $$F_D = \frac{W_L}{Ay} \cdot \frac{(V_L - V_F)}{\Delta t}$$

where

$V_L = (t + t'')\ Ay$ = velocity of larger body at start of exchange

and

V_F = velocity of larger body at end of exchange

whence, using the values of paragraph 3.2.3,

$$F_D = \frac{1103}{32.2} \cdot \frac{(0.8413)(-32.2) - (-12.639)}{\Delta t} \quad .$$

If we choose a value of 0.05 sec for Δt, F_D = -9900 lbf (-4.4×10^4 N), and if we let Δt = 0.10, F_D = -4950 lbf (-2.2×10^4 N). Actual flight test measurements gave average values of -7000 lbf (3.1×10^4 N) for F_D, which indicates that Δt is about 0.07 sec. It also shows that the cryogenic unit will be subjected to a shock of 7000/1103 or approximately 6.4 g in the vertical plane, a force which it has been designed to withstand.

Using the form of Eq. (27), we can find the force on the small, upward moving body from the following formula:

Eq. (28) $$F_D = \frac{W_s}{Ay} \frac{(V_s - V_F)}{\Delta t}$$

whence, using the values of paragraph 3.2.3,

$$F_D = \frac{335}{32.2} \cdot \frac{(34.939) - (-12.639)}{0.07} = 7071 \text{ lbs} = 21.1 \text{ g} \quad .$$

This is a very powerful force, a fact that was amply confirmed during the flight test program. The area of this extreme violence encompassed the apex of the deployed main canopy, the packed balloon and its fabric container (nicknamed the "doughnut"), the linkage and separation devices located in that region, and the top end of the inflation tubing from the cryogenic unit. Much attention was focused on this region during the test program in a successful effort to minimize the potentially destructive effects of the deceleration force.

3.4 Main Chute Opening Time

3.4.1 PRELIMINARY CALCULATIONS

In the preceding report,[1] the opening of the main chute (64-ft flat circular) was treated as the opening of a theoretical "combined" chute whose diameter was determined from the sum of the areas of the drogue and main chutes. An opening time (3.5 sec) was then determined through the use of Program P4U, which employs the formulas of the Parachute Handbook[3] for parachutes without geometric porosity.

In the revised ALBS configuration, the 42-ft ring sail main chute does have geometric porosity and an alternate method of computing opening time must be used. The Parachute Handbook offers the following formula for this situation:

Eq. (29) $$t_f = \frac{0.65\lambda_g D_o}{v_s}$$

where

λ_g = Percentage of Geometric Porosity

D_o = Nominal Parachute Diameter

v_s = Initial System velocity

whence, using a λ_g value of 22.5, and a velocity of 36.89 f/sec (11.24 m/sec) as obtained from Figure C2, at t = 2.0 sec,

$$t_f = \frac{0.65 \times 22.5 \times 42}{36.89} = 16.65 \text{ sec} \quad .$$

This appears to be an excessively long opening time. Referring back to Figure C2 we see that the projected equilibrium velocity of the system at t = 2.0 sec is 89.7 f/sec (27.34 m/sec). This means that the system, with only the drogue chute acting as a decelerator, is trying to speed up to the velocity it had before the main chute was deployed. Thus, the selected value of v_s may be too low. However, even if we arbitrarily choose a v_s of 60 f/sec (18.3 m/sec) the opening time is still over 10 sec. (When v_s is chosen as 89.7 f/sec (27.34 m/sec) the opening time becomes 6.8 sec.)

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3. Parachute Handbook (1963) Performance of and Design Criteria for Deployable Aerodynamic Decelerators ASD-TR-61-579, 2nd Ed.

Actually, a main chute combined deployment and opening time of 16 sec was selected prior to the first test at the NPTR. This value was based principally on the use of Eq. (29) above, with a v_s of 31.136 f/sec (9.49 m/sec). (See Table C3 at T = 2.0 sec.) The calculated t_f of 19.73 sec was arbitrarily revised downward, in anticipation of the effect of the centerline of the main chute, and the resultant time, 16 sec, was used to establish the time to initiate the balloon extraction step, T_o + 39 sec.

3.4.2 TEST RESULTS

As it turned out, the 16 sec value was much too long. The main chute consistently deployed in 2 sec and opened in about 3 sec in the NPTR flight tests. Thus a combined deployment/opening time of 5 sec was used in subsequent calculations and event initiation settings.

This adjustment, along with a revision (from 19 sec to 8.5 sec) of the time to "first vertical" (that is, to the completion of the system orientation change from horizontal to vertical), led to the following event schedule which was used in subsequent NPTR tests:

T_o	Release of Drogue Chute from Pendulum on C-130.
T_o + 3 sec	Finish Inflation of Drogue Chute.
T_o + 10 sec	Initiate 42-ft main chute deployment.
T_o + 12 sec	Cut main chute protective cover ("Snood") line.
T_o + 16 sec	Cut laces of balloon container.
T_o + 20 sec	Initiate balloon extraction.
T_o + 28 sec	Finish balloon extraction.

3.4.3 EFFECT OF CENTERLINE

The centerline of the main parachute is considered responsible for the drastic decrease in the estimated opening time. This line had been added to the basic parachute system configuration by the 6511 T.S., prior to the start of the flight tests, on the firm conviction that the main chute, as originally suggested, would not open after deployment. It was stated that the tension at the apex (caused by the drag force of the drogue chute) would keep the main chute canopy folds and suspension lines taut and, with the relatively low system descent velocities involved, there would be an insufficient buildup of pressure inside the canopy to cause inflation.

The centerline was constructed of 2-ply Type XXIII Nylon to withstand the 7000 lb shock load discussed earlier. It was cut to a length of 51 ft (15.5 m) and was run from the apex to lower confluence point of the main chute. Because the length of the uninflated chute is 63 ft (19.2 m), it is obvious that the centerline will become taut when the chute is deployed while the standard suspension lines and canopy folds will remain slack. Thus, there is nothing to inhibit the spreading and filling of the canopy. This unloaded condition of the lines and canopy is believed, therefore, to be the factor most conducive to the observed rapid opening. However, a penalty is involved: As the chute fills, the centerline pulls the apex inward somewhat, a situation believed responsible for the coning actions observed in the system. (See paragraph 4.6, main text.)

As a matter of interest the 6511th T. S. added another novel design feature to the main parachute to insure positive inflation. Referred to as the "snood," it is a protective Nylon cap (see Figure C4) which keeps the folds of the canopy in a tight, bunched-up configuration, during the first 2 sec of deployment when all the violence is occurring (see paragraph 3.3.3). A line surrounding the snood is then cut and the folds are free to open out. This protection of the canopy material at the start of deployment is considered to be a second key factor in the history of successful openings of the ALBS main chute during the NPTR flight series.

Figure C4. Snood for 42-ft Main Chute

4. BALLOON EXTRACTION PROCESS

4.1 General

With the main chute open (T_o + 15 sec), the system is becoming stabilized in the two-chute configuration and the way is now clear for the next major event, the extraction of the balloon from its container. At T_o + 16 sec the laces which seal that container are cut and, at T_o + 20 sec, the drag force of the drogue is applied both to the laces (to remove them) and to the top of the balloon. The discussion which follows will describe the events and cover the calculations involved in the balloon extraction process.

4.2 Initial Conditions

When the main parachute is inflated, the packed ALBS balloon rests in its laced canvas bag doughnut on top of that chute. (See Figure 9a, main text.) The 200-ft line from the drogue is connected to an extension line which passes through the center of the doughnut and is attached to the apex ring of the main chute. Thus, the drogue chute is supporting part of the overall system load. The drag force on the drogue is 362.69 lb (1613.2N) as calculated in Appendix B, Table B2.

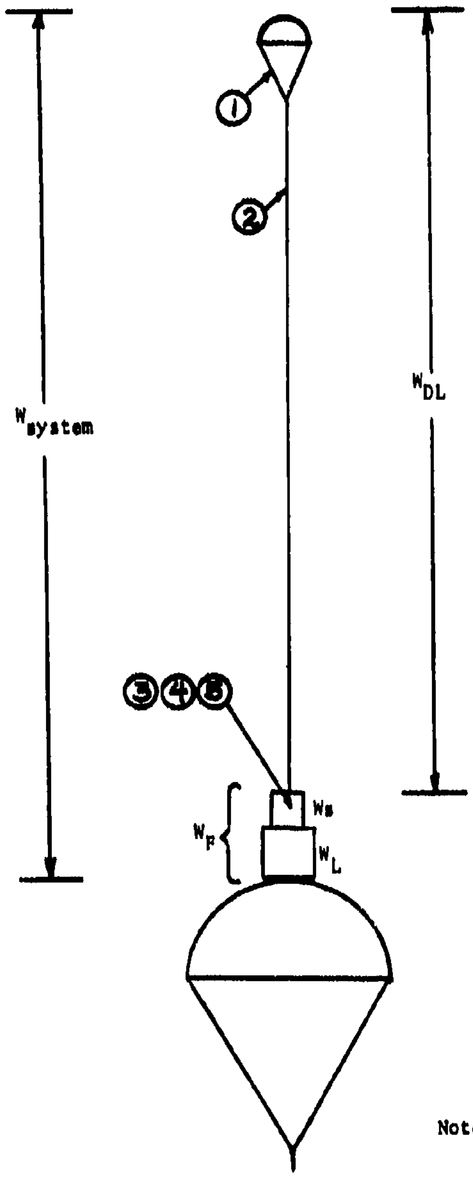
When the balloon extraction begins, the 200-ft line is disconnected from the extension line, thus removing much of the system load from the drogue. (The main chute acquires the load shed by the drogue.) The drogue still has drag, however, and it is now used to extract the balloon from its container.

4.3 Contracting Spring Effect Considerations

Because the drogue is under tension at the start of the balloon extraction process and because that tension is suddenly released, as was done at the deployment of the main parachute, the impact of line recoil had to be considered. An analysis was performed to this end, using Program P-20 to solve the equations of paragraph 3.2.2.

Unlike the main chute deployment situation, the suspended load in this case does not separate into two bodies, one of which falls freely for a time. Rather, the load starts to come apart, with the upper section rising away from the lower section to which it remains loosely attached. Figure C5 depicts the model used in the analysis. The components of the ALBS below the apex of the main canopy are ignored in this model. The system weight, W_{system}, is equated to the drag of the drogue at equilibrium, 363 lb (1615N), as computed in Appendix B.

To start the analysis, it was necessary to assign a value to the term W_s, the weight of the part of the system accelerated upward by the recoiling line. This weight would clearly include the 20 lb (89N) of miscellaneous hardware near the



System Components

Item	Description	Wt(lbf)	Force (N)
1	28-ft drogue chute	46	204.6
2	200-ft line	36	160.1
3	misc. hardware on 200 ft line	20	89.0
4	Balloon & end fittings	200	889.6
5	Balloon pack & linkage	20	89.0
W_s	See note 2	62	276
W_L	$W_L = W_F - W_s$	219	974
W_F	$W_F = W_{system} - W_{DL}$	281	1250
W_{DL}	Sum of items 1 & 2	82	364.7
W_{system}	See note 1	363	1615

NOTE 1 Only the components above the main canopy, exclusive of the balloon pack & linkage, are involved in the line recoil action.

The total system weight in this case is taken to be equal to the drag force on the drogue as calculated in Appendix B Table B-2, or, W_{system} = 363 lb.

NOTE 2 W_s is <u>not</u> the sum of the weights of items 3, 4 and 5. It represents the sum of item 3 and part (42 lb, 187 N) of item 4. See para.C.4.3 of text)

Note: 1 pound force (lbf) - 4.448 Newtons (N)

Figure C5. Weight Distribution for Balloon Extraction Event 4b, Prior to Extraction base of the line, plus some length of the balloon which would also be snatched up from the doughnut during the line recoil. Using a trial and error method, the author arrived at a figure of 42 lb (107N) as the weight of the balloon component of W_s. This is the weight of 21.6 ft (6.5 m) of balloon, with the balloon weighing 200 ÷ 102 or 1.96 lb/ft (21.61 N/m). Note that the 21.6-ft length of balloon is the sum of parameters x and a' on Table C3 which summarizes the analysis data. The value assigned to W_s is, then, the sum of the hardware weight (20 lb) and the balloon weight (42 lb), or 62 lb (276N).

From Table C3 it can be seen that the time to no tension, t, is approximately 0.28 sec, while the total no-tension time (t' + t''') is approximately 1.8 sec.

Even though recoil is indicated, there is some question as to whether it is present to the extent shown on Table C3. The amount of initial loading on the rugged drogue line (2 plies of 12,000 lb strength webbing) is quite light (281 lb) and the assumption that this webbing behaves as 2 in 1 Nylon (see paragraph 3.2.2, Eq. (1)) may not be entirely valid. Moreover, part of this recoil is believed to be expended in pulling the laces out of the doughnut pack and in overcoming the friction associated with snatching up 21.6 ft of Z-folded and coiled balloon material.

Despite the doubts, the author carried out the balloon extraction computation using the data from Table C3 and compared the results with a similar run in which the data were not used. The resulting comparison showed that the contracting spring effect is minimal in the balloon extraction process and can be ignored. Figure C6 summarizes the balloon extraction computations carried out without use of the contracting spring data. Note that the balloon is fully deployed in 8 sec, which is in good agreement with data from the NPTR tests. (See paragraph 4.5, main text.)

It is interesting to note on Table C3 that the data pertaining to the parameter y do not apply here. (In the main chute extraction, y was the point at which the smaller and larger bodies exchanged momentum.) In this case the rising body goes to the theoretical distance above no tension where its velocity becomes zero. There is no exchange of momentum. The shock occurs when the body falls back down to the line stretch point and is less than 1g.

Table C3. ALBS Contracting Spring Data Summary for Balloon Extraction, Event 4b

Symbol	Parameter	English Units	Metric Units
F_k or W_f	Total suspended wt, less drogue and line	281 lbf	1250 N
$-F_m$ or $-W_s$	Residual wt after release of W_L	-62 lbf	-276 N
Ay	Gravitational constant	32.2 ft/sec^2	9.81 m/sec^2
y_c	Specified separation distance	N/A	N/A
M_s or m	Small mass (-Ws/Ay)	1.933 slugs	28.21 kg
x	Stretch distance (.0118 F_k + 4.9012)	8.217 ft	2.50
k	Spring constant F_k/x	34.197 lb/ft	449 N/m
t	Time to no-tension point (n.t.)	.2799 sec	.2799 sec
$-v_{so}$	Initial separation velocity, at time t	N/A	N/A
v	Velocity of small mass, at time t	29.36 f/sec	8.95 m/sec
$-v_{y(L)}$	Velocity of large mass, at time t	N/A	N/A
$-y_L$	Free fall distance, at time t	N/A	N/A
$-y_{so}$	Initial separation distance ($-y_L$-x), at time t	N/A	N/A
a'	Theoretical max. distance above n.t.	13.38 ft	4.08 m
t'	Time to a' (theoretical)	.9117 sec	.9117 sec
t + t'	Time from release to a' (theoretical)	1.192 sec	1.192 sec
y	Max. actual distance above n.t.	N/A	N/A
v_{ys}	Velocity of small mass at y	N/A	N/A
$-v_{so_f}$	Final sep. velocity, at y (Vs)	N/A	N/A
t''	Time from no tension to y	N/A	N/A
t + t''	Time from release to y	N/A	N/A
$-v_F$	Velocity of combined mass at t + t''	N/A	N/A
t'''	Time to eliminate line slack	.9117 sec	.9117 sec
v_T	Terminal velocity of combined mass	N/A	N/A
t'' + t'''	Total no tension time	1.823 sec	1.823 sec
t + t' + t'''	Time to reapply full load	2.103 sec	2.103 sec

Program P13A

ALBS BALLOON
EXTRACTION COMPUTATION

(t/t_f) T	t(sec)	psf q	fps Δv	fps $-v$	lb D	ft H	lb W	fps Ve	$\Sigma\Delta H$
DROGUE CHUTE TRACK									
0	0		-	-43.72	-	23600	122	-	0
.02	.16	.8025	6.0	-37.72	271.78	"593.5	125.6	25.358	- 6.52
.04	.32	.6435	3.538	-34.185	217.93	"587.7	129.2	" .727	- 12.27
.06	.48	.5596	2.20	-31.99	189.51	"582.6	132.8	25.090	- 17.56
.08	.64	.5118	1.395	-30.59	173.33	"577.4	136.4	" .449	- 22.57
.10	.80	.4840	.8798	-29.71	163.91	"572.61	140.0	" .803	- 27.39
.12	.96	.4[illegible]63	.5363	-29.17	158.55	"567.9	143.6	27.152	- 32.6
.14	1.12	.4560	.3008	-28.87	155.79	"563.25	147.2	" .496	- 36.47
.16	1.28	.4570	.359	-28.74	154.78	"558.6	150.8	" .837	- 41.36
.18	1.44	.4576	.0189	-28.72	154.96	"554.05	153.4	28.173	- 45.95
.20	1.60	.4607	-.0649	-28.78	156.00	"549.46	158.0	28.505	- 50.55
.30	2.40	.4954	-.2411	-29.75	167.76	"526.1	176.0	30.108	- 73.92
.40	3.20	.5424	-.2733	-31.07	183.71	"501.8	194.0	31.627	- 98.24
.50	4.00	.5928	-.2730	-32.44	200.76	"476.4	212.00	33.074	-123.65
.60	4.80	.6442	-.2653	-33.79	218.57	"449.9	230.00	34.456	-150.14
.70	5.60	.6959	-.2562	-35.09	235.67	"472.31	248.00	35.783	-177.69
.80	6.40	.7477	-.2473	-36.34	253.23	"399.74	266.00	37.059	-206.26
.90	7.20	.7996	-.2392	-37.55	270.82	"364.2	284.00	38.289	-235.82
.98	7.84	.8412	-.2330	-38.49	284.90	"339.8	298.4	39.243	-260.16
1.00	8.00	.8517	-.2316	-38.72	288.42	"333.7	302	39.478	-266.34

MAIN CHUTE TRACK Same initial conditions except Wi = 1520 lb
- 122 lb
= 1398 lb and $(C_D S_o)$ = 1080.63

(t/t_f) T	t(sec)	psf q	fps Δv	fps $-v$	lb D	ft H	lb W	fps Ve	$\Sigma\Delta H$
0	0	-	-	-43.72	-	23600	1398	-	0
.02	.16	1.140	-.5998	-44.32	1232.04	"592.9	1394.4	48.05	- 7.04
.04	.32	1.1599	-.3084	-44.628	1253.55	"585.8	1390.8	47.967	- 14.17
.10	.80	1.203	-.2989	-45.92	1299.92	"564.02	1380.0	47.783	- 35.97
.50	4.00	1.223	+.0549	-46.61	1321.93	"414.5	1308.0	46.401	-185.53
.80	6.40	1.176	+ -	-45.62	1271.0	"303.8	1254.0	45.28	-296.24
.90	7.20	1.159	+.0709	-45.27	1253.0	"267.4	1236.0	44.99	-332.6
1.00	8.00	1.143	+.0715	-44.91	1234.92	"231.3	1218.0	44.637	-368.67

@ T = 1.0

$\Sigma\Delta H$ main = -368.67 ft

$\Sigma\Delta H$ drogue = -266.34 ft

Δ = 102.33 ft

length of balloon 102 ft

Registers	00	01	02	03	04	05	06	07	08	09	10	11	12	13
IN	-	$-v_i$ -43.72	$t_f/50$ .16s	W_i .122	ρ MSL .001189	- 0	H_i 23600	$\sigma_{H-1000'}$ .48779	σ_H .47115	$W_B/0$ 200	$(C_D S_0)_{max}$ 338.063	Count No 50	0	$W_{OT}/-\Delta H$ 102
OUT	q	$-v_{1,2}$	-	W	-	-	$H_{1,2,3}$	D	-	$-\Sigma\Delta H$		-	$V_e/-v$	$-\Delta H$

Contracting Spring Data
(from P-20):

(Not used)

Subject: Event 4b

28' Drogue chute (r. slot)
42' Main chute (r. sail)

LEGEND

D	Drag force
W_W	System Weight 1520 lb
D_0	Chute nominal dia. 28 ft
v_i	initial(release)velocity
v	instantaneous Velocity
Δv	Change in velocity
t_f	Total Extraction Time 8.0s
t	actual time(s)
$\Sigma\Delta H$	summation of height changes
W_i	initial weight $(0.1\ W_B + W_{OT})$
W	Instantaneous Weight
q	dynamic pressure
ρ	atm. density
H_i	release altitude
H	instantaneous altitude
σ	density ratio $\rho/\rho o$
W_B	Weight of ALBS balloon
W_{OT}	" other components suspended on drogue
C_D	coeff. drag (chute) .55
S_0	Ref. Area of chute
Ve	Projected Equilibrium Velocity for system of Weight, W

Figure C6. Balloon Extraction Event 4b, Computations Without Use of Contracting Spring Data

Appendix D

Summary Report, Airborne Cryogenic Consultation, Charles F. Sindt,
Cryogenics Division, National Bureau of Standards

1. INTRODUCTION AND BACKGROUND

The purpose of the air launch balloon system (ALBS) is to fill a balloon with helium gas while the system is descending on a parachute at some altitude. The helium is stored in the liquid state in a cryogenic unit. The principle of operation of this unit was to convert part of the liquid helium flowing from the attached liquid helium dewar to high temperature gas, then to mix this high temperature gas with very cold gas in the correct proportion to get the desired final gas temperature for inflating the balloon. The hot gas was heated in a hot bed exchanger; the cold gas was converted from liquid by heat exchanging with ambient air. The final configuration of the system is to be extracted from a flying aircraft. A small parachute extracts the system from the aircraft; the system is then allowed to free fall about 60 m before a larger parachute is deployed. The small parachute then extracts the balloon from a bag secured to the canopy of the large parachute. Next, the ALBS cryogenic unit provides the helium gas to fill the balloon. After filling the balloon, the cryogenic unit separates from the rest of the system and descends to the ground on a three-parachute cluster. The filled balloon ascends to the desired altitude carrying the large parachute and a payload. The large parachute is later used to recover the payload.

The prototype ALBS was to be carried to the launch altitude of 7600 m by a large ground launched balloon. This method of air launching the system does not impose high loads at the launch, therefore, the system was designed to accomodate only those peak loads that occur when the large parachute opens after the system is released from the carrier balloon. Also, the system did not need to be aerodynamically clean nor compact as would be desired for a unit that was to be launched from a flying aircraft. Since compactness was not required, two existing dewars were used as the liquid helium containers instead of purchasing one new vessel. Using the two dewars instead of one, complicated the system plumbing but was less expensive and time consuming than purchasing one new, especially constructed dewar. The two existing dewars weighed less than any one available dewar of the correct size. The dewars each held 24.5 kg of liquid helium; with five percent ullage, the dewars held a total of 46.6 kg of liquid helium, the mass of gas desired for filling the balloon at the altitude.

The two dewars were mounted one on each side of a hot bed heat exchanger. This arrangement results in a balanced system weight about the heat exchanger. The dewars were connected in series by a vacuum insulated line, so they emptied consecutively. No additional valves or controls were needed between the dewars. Each dewar required modification since they were designed to provide supercritical hydrogen at the discharge. The modification included the removal of all of the internal hardware and installation of a new vacuum insulated, liquid withdrawal tube as well as two liquid level sensors. Installation of the new internal assembly necessitated a new seal in the double-walled titanium dewar. Because the equipment for welding the titanium vessel was not available, a filled epoxy was used in a threaded joint to make the low temperature, vacuum tight seal. This joint was successful as both dewars retained insulating vacuum through a number of thermal cycles from ambient to liquid helium temperature. Figure D1 is a schematic diagram of the flow system, except it shows one single dewar system.

The hot bed heat exchanger contained 73.4 kg of 3/8 in. diameter aluminum oxide balls. This bed was designed to store the heat required to convert 46.3 kg of liquid helium to gas at 260 K. The design bed temperature was 1005 K with a maximum operating limit of 1060 K. A 2000 W electrical heater heated the bed, and temperature was maintained with a thermostat control. The heat exchanger was insulated with a 6.4 mm thick blanket and a 57 mm annulus of evacuated powder. The estimated heat loss of the heat exchanger at 1005 K was 400 W.

The ALBS used gas pressure to force the liquid helium from the dewars through the system at a mass flow rate of 0.16 kg/sec. The helium gas used for pressurization was stored in a 0.011 m^3 aluminum cylinder at 32.4 MPa pressure. The aluminum cylinder was reinforced with a glass fiber, epoxy wrap.

Valves used in the system for controlling the liquid and gas flow were industrial weight, solenoid valves designed for cryogenic service. The valve used in the helium gas pressurization line was a "flight weight" solenoid valve.

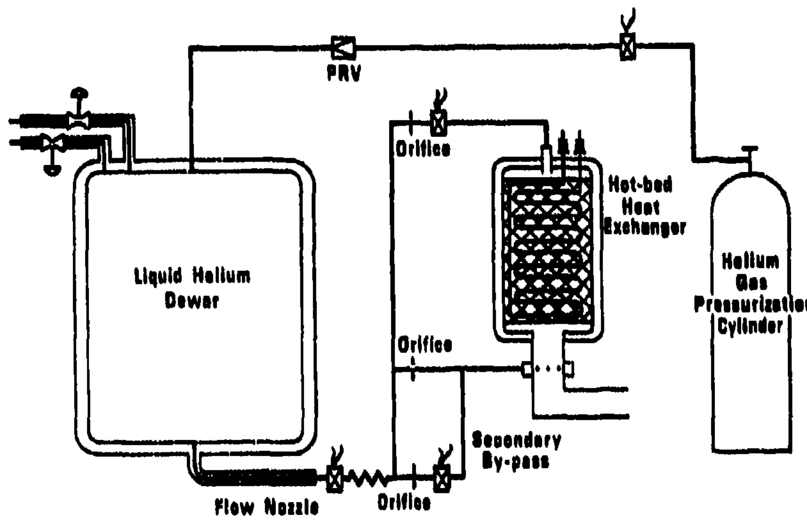


Figure D1. Schematic Diagram of Proposed Single-Dewar System

An electric timer with switches controlled the valve opening sequence. The timer and the valves were powered by a 24 volt battery.

The system components were mounted on an aluminum frame shown in Figures D2 and D3. This frame was designed to support the components under a seven g load. To assure that the frame was strong enough to withstand the forces at seven g's, the mounting pads for the dewars and the hot bed were loaded with lead weights equivalent to the loads expected at seven g's. A small additional dynamic load was then applied to each pad. A four foot by eight foot by one-half in. thick piece of plywood was attached to the base of the frame to provide a surface for installing several layers of crushable pad. The crushable pad was to cushion the landing of the cryogenic unit as it descended on the recovery parachutes. A small aluminum rail extended around each dewar to protect them during the ground launch. The cryogenic system weighted 314 kg without liquid helium.

The ALBS was designed to operate independent of controls other than a 10 sec switch closure which initiated the clock timer. The final sequence of system events were established as follows: The system started functioning 10 sec after the timer switch closure when the dewar pressurization valve opened and the dewars were pressurized to 338 kPa. Twelve sec later the liquid valve at the dewar exit opened and helium started flowing into the mixing area at the base of the heat exchanger. The secondary bypass valve opened 2 sec later to increase the cold gas flow. At 9 sec after the liquid flow started, the valve to the heat

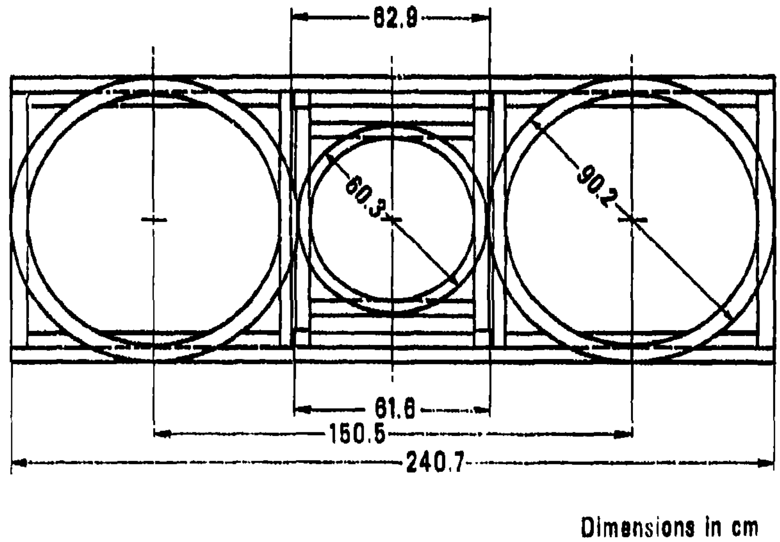


Figure D2. Outline Diagram of Two-Dewar System

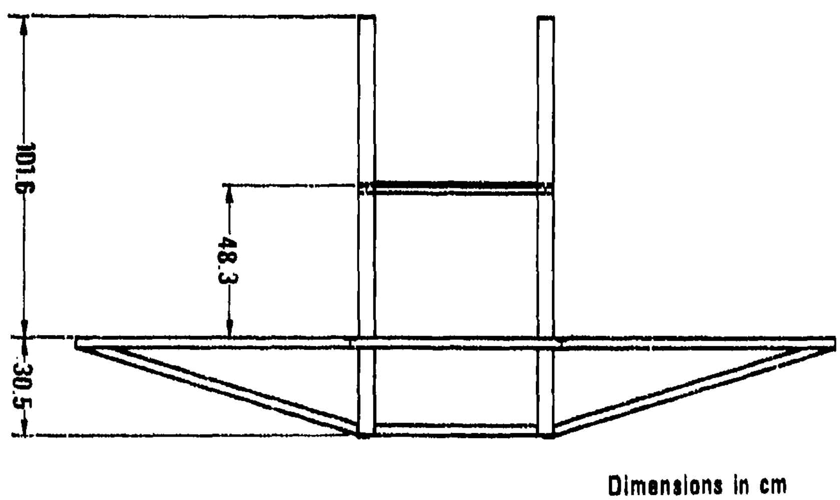


Figure D3. Supporting Frame for Two-Dewar System exchanger opened. Full flow was established 20 sec after the start of liquid flow; 170 sec after the start of liquid flow, the first dewar emptied. This resulted in less flow resistance in the liquid system and a higher liquid flow rate. To help compensate for an unbalance in the flow split between the heat exchanger and the cold bypass that occurred with higher flow rates, the secondary bypass flow was terminated. Even with the closing of the secondary bypass, the flow rate increased 15 to 20 percent and this increased flow rate continued until the second dewar emptied at about 300 sec.

From the mixing chamber at the base of the hot bed heat exchanger, the gas flowed through a 10-cm diameter tube into a 2.4 kg bed of 3/8 inch diameter balls of aluminum oxide. This second bed was not heated but served to increase the mixing of the hot and cold gas streams and to reduce the maximum temperature spike which occurred at the opening of the valve to the heat exchanger. From this mixing bed, the gas flowed into a 16.5-cm diameter tube. This tube which terminated at the top of the frame was the gas supply tube for the balloon.

All of the flow paths from the liquid helium dewar contained replaceable orifices which were used to adjust the flow rates. Openings in these orifice plates were sized during a test program in which a number of tests were conducted to establish the correct dewar pressure and flow rates to get an average mass flow rate of 0.16 kg/sec at an average gas temperature of 260 K.

For the final test both dewars were cooled for 24 hr, then the dewars were filled with liquid helium 1 h prior to the run of the system. One half-hour before the run, the dewar vents were closed. The dewar pressure rose to 75 kPa before the run started. When the vents were closed, the dewars contained 48.5 kg of liquid helium which was about 5 percent over the required mass. The run lasted 295 sec. The peak gas temperature was 355 K with the temperature remaining above 320 K for less than 15 sec. The minimum gas temperature was 176 K with the temperature remaining below 220 K for less than 20 sec. The maximum flow rate was about 0.2 kg/sec. The average flow rate was 0.165 kg/sec and the average discharge gas temperature was 249 K. The system delivered 5 percent more mass than required, but the average gas temperature was 5 percent low. Since the larger than design mass would nearly offset the loss of lift in the balloon due to the low gas temperature, the system was accepted as ready for the flight test in this configuration.

In addition to building the ALBS we built an enclosed superstructure to hold the main parachute, the air launched balloon, the balloon's payload, and the parachutes for recovery of the cryogenic unit. The enclosure of the superstructure was 96 cm by 137 cm by 198 cm high. The frame of the superstructure had four lugs at the base for attaching it to the cryogenic unit with four 1/2 in. bolts. The superstructure frame carried clevis mounts for attaching all of the parachutes, therefore, it was designed to carry the loads that were generated when the main parachute opened. At the time the main parachute opened, the maximum expected load was 4920 kg. Since the possibility existed that this load could be applied to just two of the four clevis mounts attached to the parachute, the frame was designed to support 4920 kg on two of the four parachute strap mounts.

Availability of aluminum tubes and an aluminum welding capability influenced our decision to use aluminum tube construction with welded joints for the superstructure frame. Figures D4 and D5 show the aluminum frame. The frame was enclosed at the sides with 1/4 in. thick plywood and a 1/2 in. thick plywood floor was installed. The clevis mounts for the parachute straps were cut from aluminum and were designed with an incorporated clamp for clamping the mount to the aluminum tube frame. This unit weighed 93 kg.

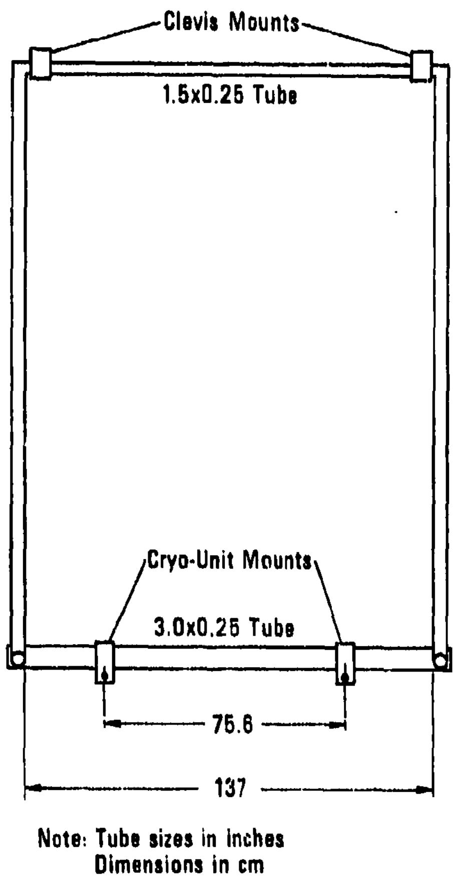


Figure D4. Cryogenic Unit Superstructure Frame Work (Side View)

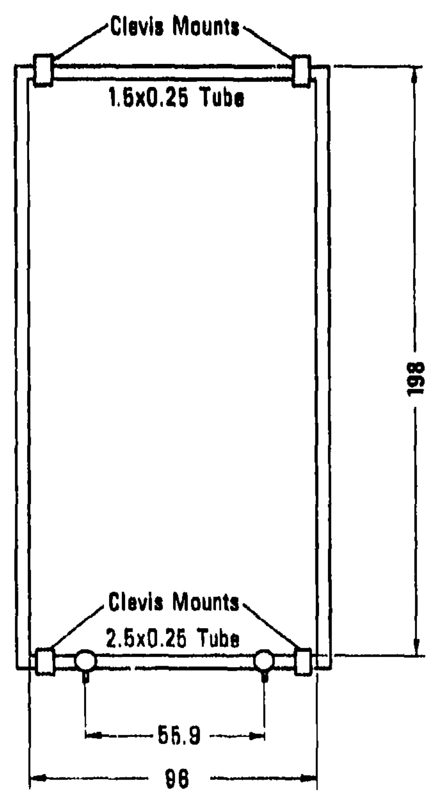


Figure D5. Cryogenic Unit Superstructure Frame Work (Rear View)

Because the stresses in some of the aluminum tubes were high, stresses were calculated using a simplified model. This analysis is presented in Section 1.1.

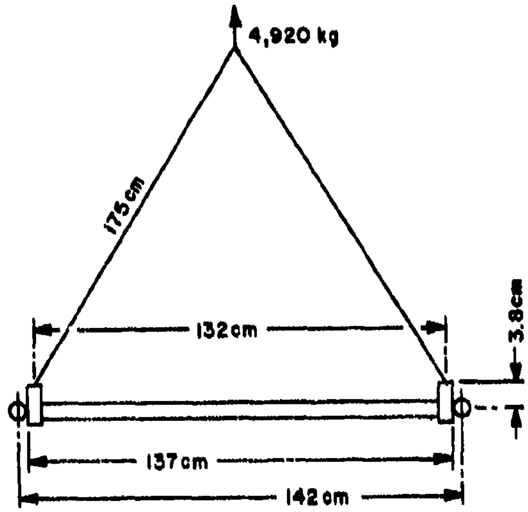
The ALBS was taken to Truth or Consequences, New Mexico for the demonstration flight test. About 18 hr prior to the flight time, the dewars were cooled to liquid helium temperature. One dewar was filled to 100 percent full. The second dewar was filled to about 25 percent full. Some difficulty was encountered during the filling because of thermally induced pressure oscillations which developed in the vent system. Adjustments in the vent rates reduced the oscillation to an acceptable level. The dewars were completely filled with liquid helium about 2-1/2 hr prior to the ground launch. The vents were closed at about 75 min before the launch. The dewar pressures rose to about 120 kPa gauge by launch time. This pressure rise rate was acceptable if the system was to function within 70 min from the ground launch. The system was lost during the launching of the carrier balloon as this balloon failed to ascend to altitude.

1.1 Formulas for Stress and Strain (Roark[1])

The maximum stress in the superstructure frame occurs when the large parachute deploys. The total force was estimated to be 4920 kg based upon force measured in an actual parachute test program. Assuming that this total load may be applied to two of the four support straps connecting the parachute to the superstructure, any two of the adjacent clevis mounts and the tube between them must be designed to momentarily support this load. For the stress analysis, the straps were assumed to be 175 cm long. Since the maximum stress will develop in the longest member, the stress in the 142 cm long tube at the top of the superstructure was the only stress calculated.

If the clevises on the 142 cm long tube are used for attaching the large parachute the following force diagram applied.

1. Roark, R.J. (1965) Formulas for Stress and Strain, McGraw-Hill Book Co., New York.



Assuming that the 142 cm long tube is a free-ended column, which it really is not, the maximum stress is given by Roark[1] as

$$S = \frac{P}{A}\left\{ 1 + \frac{e_1 c_1}{r_1^2} \sec \left[\frac{P}{EA}\left(\frac{L}{r}\right)^2\right]^{1/2} \right\}$$

for an eccentrically loaded column.

In this equation P is the load, A is the cross section area, e is the eccentricity of the load, c is the radial distance to the extreme fiber, r is the radius of gyration with respect to the axis of the tube, E is the modulus of elasticity, and L is the length between loaded ends.

The maximum stress using the aforementioned assumptions is 149 MPa. If the clevis mounts on the 96 cm long member are used instead and the mounts are as close to the corners as possible, the maximum stress in the 142 cm long member can be reduced to about 100 MPa. The reduced stress results from a slight reduction in the eccentricity of the load. (149 Megapascals $\simeq$ 21, 610 psi.)

The other members of the frame that are exposed to high stress are the two 3-in. diameter tubes that carry the cryogenic unit. Again we assume that one tube must support the entire load and that the tubes are free-ended beams. This becomes a simple beam problem where the maximum stress is as follows:

$$S = \frac{mc}{I}$$

where S is the stress, m is the maximum moment, c is the radial distance to the extreme fiber, and I is the moment of inertia with respect to the neutral axis or, in this case, the centerline of the tube. For the tubes used in the frame, the maximum stress is 152 MPa. All of the stresses calculated are less than the recommended maximum stress using a 1.5 safety factor. The 1.5 safety factor is based on the yield stress of the material and since all of the frame material is 6061-T6 aluminum, the yield stress is 241 MPa.

Several other factors add to the actual safety factor. These are: (1) the ends of both beams considered are actually welded to other members, so some of the load is transmitted to other members and (2) in this application, the maximum assumed load is only momentary and, therefore, of such short duration that yielding of the beam might not occur even if the yield stress is slightly exceeded.

Appendix E

ALBS Balloon Mid-Air Inflation Computations

1. INTRODUCTION

Note: This appendix has been extracted (in condensed form) from para 4.4.6, main report, of a previous report AFGL-TR-0196.[1] The numerical values used here are based on the values of Table 5 in this report.

At the end of event 4c on Table 5, the balloon has been fully extended and is taut (see Figure 21 in the main report). If we assume that the uninflated balloon contributes no effective drag, the total system drag area is the same as it was before the extraction, 1419.31 ft^2 (131.85 m^2), which is the sum of the effective drag areas of the drogue and the main chute. (The balloon is treated here as just an added line between the two chutes.) The drag force on the drogue is then 442 lb (1877N), and that on the main chute is 1347 lb (5991N) (calculated per the method of Appendix B).

When the balloon inflation command is given, the liquid helium in the cryogenic unit below the main canopy is converted to the gaseous state, warmed and transferred up to the waiting balloon. The gas starts to flow almost instantaneously, but an estimated 5 min is required for transfer of all the gas. During this time the ALBS array loses altitude steadily, but at a decreasing rate of descent.

Two interesting and interacting physical changes occur simultaneously during the inflation process, both of which have a pronounced effect on the dynamics of the event:

1. Carten, A. S., Jr. (1976) The Flight Test Aspects of the Air-Launched Balloon System Development Program, AFGL-TR-76-0196.

1.1 The Increase in Buoyancy

As the helium enters the balloon it adds buoyancy (positive lift), neutralizing some of the weight previously supported by the parachutes. A steady diminution of system weight (W_S) is apparent on Table E1, which was generated by Program P14B (see paragraph 2) and which lists changes in various system parameters during the balloon inflation. Because W_S is decreasing, there is an accompanying decrease in system descent velocity. This can be observed in the column headed V_e on Table E1. (Not all of the deceleration shown in the V_e column is the result of the added buoyancy. Some is due to increased system drag, as explained in the next paragraph, and to increasing atmospheric density.)

1.2 The Increase in System Drag

The gas bubble formed at the top of the balloon adds to the total effective drag area of the system $(C_DS_o)_S$. It will be seen from Table E1 that $(C_DS_o)_S$ increases during inflation until the drogue is cut away. At that point, there is a step decrease to show the loss of (C_DS_o) for the drogue. The reduced $(C_DS_o)_S$ value then becomes the starting point for a new incrementally-increased system effective drag area, the augmentation of which persists until the balloon is fully inflated.

The increased system drag area serves to decrease system equilibrium descent velocity, V_e. (As noted above, additional deceleration is being caused simultaneously by the buoyancy and atmospheric density effects. Thus, the values of column V_e reflect the combined reductions in system descent velocity.) Dynamic pressure, q, also decreases, as does the total system drag, D_s. (There is a step increase in q, when the drogue is cut away, but the decrease soon continues.)

2. PROGRAM P-14B

Table E1 shows changes in many system parameters over fixed intervals of height (200 ft). The starting altitude is 23,200 ft. The starting equilibrium velocity is the system V_e at the end of event 4c.

Program P-14B was developed* primarily to determine the time required for the system to fall through each 200-ft interval of height, taking into effect the

*Program P-14B was originally developed by the author for use on a programmable desk calculator. That method proved to be too time-consuming, however, and the program was translated into FORTRAN by Mr. Robert Vesprini of Emmanual College.[2] At the same time certain refinements were introduced which are incorporated in this appendix.

2. Vesprini, R.L., and Hagan, M. P. (1977) Report on Atmospheric Environment Interactions With Free and Tethered Balloons, AFGL-TR-77-0100, Final Report on Contract F19628-74-C-0039.

decreasing velocity discussed above. Incremental and cumulative time values so determined are shown under columns Δt and $\Sigma\Delta t$ respectively. The balloon inflation is assumed to be complete when the cumulative time value is 300 sec and the designated amount of helium (see next paragraph) has been transferred. The altitude associated with this time is the event completion altitude.

2.1 Buoyancy Computations

It is assumed that the total required quantity (see paragraph 3) of helium, 102.44 lb (455.7N) is transferred linearly with time over 300 sec (5 min). On that basis, the amount transferred (ΔMHe) during any 200-ft interval would be a function of the time (Δt) required to descend that distance. Whence, $\Delta MHe = \Delta t \cdot \frac{102.44}{300} k$. For example, during the first 200-ft interval (23,200 ft - 23,000 ft) the amount of helium transferred is 1.48 lb (6.58N), which is the result of the calculation 4.295 sec $\times \frac{102.44}{300} \times 1.0077$, or 4.295 sec $\times$ 0.3441, where 0.3441 is a constant transfer rate in lb/sec and 1.0077 (k) is an empirical correction factor to account for the fact that the system's descent rate is slowing down. The quantity 1.48 lb appears as the initial value in the $\Sigma\Delta$MHe column, which is a cumulative record of the amount of helium transferred as the event proceeds. When the incremental quantity of helium (lb) is multiplied by the lift to mass (L/M ratio (lb lift per lb of mass) for helium at the pressures and temperatures involved, the amount of buoyancy gained per time increment is obtained (see note *). Cumulative values of buoyancy appear in the $\Sigma\Delta$L column.

*The lift to mass (L/M) ratio plays a key role in determining the amount of buoyancy being added to the balloon as helium is transferred upward from the cryogenic unit. ("Mass" here is used to denote quantity in lb. It is not used in the usual sense that mass equals weight/gravitational constant.) We obtain the L/M ratio by dividing the specific lift of the incoming gaseous helium by the density of that helium. Specific lift in turn, is obtained by subtracting the density of the gaseous helium from the density of the ambient air. Program 14B calculates air and helium densities for each 200-ft interval of height, in order to obtain a continuously upgraded L/M ratio, as follows:

(a) Density is a function of gas temperature and pressure. The pressure is assumed to be that of the standard atmosphere and is generated from stored data. The temperatures of the air and helium are different from standard atmosphere values, however. The air temperatures chosen are those of the WSMR in January. The helium temperature is fixed at 250°K, which is typical of the cryogenic unit output.

(b) If we let the density, ρ_2, of Helium at a particular height be equal to that at another height, ρ_1, times the temperature and pressure ratios shown:

$\rho_2 = \rho_1 \frac{T_1}{T_2} \cdot \frac{P_2}{P_1}$, and if we let ρ_1 be sea level density for gaseous helium (0.01056 lb/ft^3) at standard temperature (288°K) and pressure (1 Atmosphere), we get the relationship: Eq. (E1):

2.2 Gas Volume Computations

The density of all of the helium in the balloon (as opposed to that of just the incoming gas) is now divided into the $\Sigma\Delta MHe$ value for each 200-ft altitude increment to obtain the volume occupied by the gas, V_b. (See note †.) The gas volume is assumed to be that of a sphere, whence the diameter, d_b, is obtained by the relationship $d_{sphere} = (V\ 6/\pi)^{1/3}$. Knowing the diameter, we can obtain the cross-sectional area ($\pi d^2/4$) or S_o. This is then multiplied by a value of 0.5 (C_D for the bubble) to give us $(C_D S_o)_B$ or the effective drag area of the balloon; $(C_D S_o)_B$ in turn augments the value of $(C_D S_o)_S$.

$$\rho_{2_{He}} = 3.0413\ \frac{P_2}{T_2}$$

We then solve for the density of the incoming helium at a given height interval by use of Eq. (E1), letting $T_2 = 250^oK$, and P_2 the stored standard atmosphere value of pressure for that height, as listed on Table E1.

(c) We can establish a relationship for air density similar to Eq. (E1):

$\rho_2 = 0.07651 \times \frac{288}{T_2} \cdot \frac{P_2}{1}$ where 0.07651 lb/ft^3 is the sea level density of air or

Eq. (E2), $\rho_{2_{Air}} = 22.035\ \frac{P_2}{T_2}$

We then solve for air density at a particular height interval by use of Eq. (E2) letting T_2 and P_2 be the stored values for that height, as shown on Table E1.

†The gas is assumed to enter the balloon at a constant temperature (in this case 250°K. But, as the system descends, adiabatic heating of the gas already in the balloon occurs, at the rate of 4°K per 1000 ft of descent (0.8°K/200 ft). (Other heat sources such as radiation and conduction through the balloon film are not considered.) Thus, the temperature used here to determine gas density at a particular height must be based on both the temperature of the incoming gas and that of the on-board adiabatically warmed gas.

We can solve for He density by means of Eq. (E1) above, using a stored value of P_2 and determining the value of T_2 by an appropriate means.

$$\text{Let } T_2 = \frac{\Sigma\Delta MHe(T_o + 0.8) + \Delta MHe \cdot T_{He}}{\Sigma\Delta MHe + \Delta MHe} \quad \text{Eq. (E3)}$$

where $\Sigma\Delta MHe$ = Mass of helium already in balloon at start of this increment

ΔMHe = Helium added during this increment

T_o = Temperature of gas already in balloon

T_{He} = Temperature of incoming gas (assumed to be 250°K here)

Then, solving for T_2, and knowing that volume = mass/density, we determine the volume of the gas from the relationship

$$\text{Eq. (E4)}\quad V = \frac{\Sigma\Delta MHe + \Delta MHe}{3.0413\ P_2} \cdot T_2$$

As inflation proceeds, the expanding bubble causes the balloon reefing sleeve to open up gradually so that slack material is protected. Because of the relatively low altitude, the bubble diameter (d_B) remains small, reaching a maximum diameter of only 30 ft (9.14 m) at full inflation. The volume of gas in this bubble, approximately 14,300 ft^3 (405 m^3) is less than 10 percent of the fully-expanded volume at float altitude. Moreover, although the volume is increasing by virtue of added gas, the rate of increase is slowed by the effect of increased atmospheric density as the system descends.

3. CUTTING AWAY THE DROGUE; END OF INFLATION

At some point the drogue must be cut away, both to eliminate unnecessary weight from the system – which will rise to float altitude – and to avoid possible entanglement when the drogue becomes very lightly loaded and subject to collapse. Table E1 indicates that the drogue is cut away when the buoyant lift in the balloon exceeds 275 lb (1223N), which is more than enough to keep the balloon upright after the support furnished heretofore by the drogue is removed.

The inflation is shown to be complete when the system has descended to 12026 ft (3666 m).

The balloon is now ready to be cut away from the cryogenic unit and frame and to ascend to float altitude with its payload. Note that the 102.44 lb (455.6N) of helium provides 612.26 lb (2723.3N) of lift. This is equal to a free lift of 6.5 percent, less than the desired 10 percent. If the temperature of the incoming helium is raised to 255°K, the free lift becomes 8.8 percent and the completion altitude is 12,046 ft. (From a separate run of Program P-14B, not included in this report.) Variations in air temperatures are also capable of changing the free lift. Thus, Table E1 must be considered simply as representative run, subject to some variation. (As it turned out, the cryogenic unit prepared for the January 1978 test had somewhat more than 102.44 lb of LHe aboard, while the payload to be taken to altitude was 565 lb, rather than 575. Free lift probably would have been ample if the flight had taken place as planned.)

H (ft)	σ	P (Atm)	Air Temp. °K	L/M Ratio	Δt (sec)	ΣΔt (sec)	V_e (fps)	q (psf)	ΣΔMHe (lb)	He Temp. °K	ΣΔL (lb)
23200.	.47779	.4017					-47.00				
23000.	.48108	.4051	259.0	5.993	4.295	4.295	-46.14	1.2176	1.480	250.0	8.87
22800.	.48446	.4086	259.4	5.994	4.360	8.654	-45.61	1.1985	2.957	250.4	17.73
22600.	.48784	.4121	259.8	5.994	4.408	13.062	-45.13	1.1815	4.458	250.8	26.72
22400.	.49122	.4157	260.2	5.994	4.453	17.515	-44.68	1.1662	5.974	251.2	35.81
22200.	.49460	.4192	260.6	5.995	4.498	22.013	-44.25	1.1515	7.507	251.6	45.00
22000.	.49798	.4227	261.0	5.995	4.541	26.554	-43.84	1.1378	9.054	252.0	54.28
21800.	.50145	.4264	261.4	5.995	4.584	31.138	-43.43	1.1245	10.617	252.4	63.66
21600.	.50492	.4300	261.8	5.995	4.626	35.764	-43.03	1.1117	12.194	252.8	73.10
21400.	.50840	.4337	262.2	5.995	4.669	40.433	-42.64	1.0993	13.786	253.1	82.65
21200.	.51187	.4373	262.6	5.995	4.711	45.144	-42.26	1.0872	15.393	253.5	92.28
21000.	.51534	.4410	263.0	5.995	4.753	49.897	-41.89	1.0753	17.014	253.9	102.00
20800.	.51890	.4448	263.4	5.995	4.795	54.692	-41.52	1.0638	18.649	254.3	111.80
20600.	.52247	.4486	263.8	5.995	4.838	59.530	-41.16	1.0524	20.299	254.7	121.70
20400.	.52603	.4523	264.2	5.995	4.880	64.410	-40.80	1.0412	21.964	255.1	131.67
20200.	.52960	.4561	264.6	5.995	4.923	69.333	-40.45	1.0302	23.643	255.5	141.74
20000.	.53316	.4599	265.0	5.995	4.966	74.299	-40.10	1.0194	25.337	255.8	151.89
19800.	.53682	.4638	265.4	5.995	5.009	79.308	-39.75	1.0087	27.046	256.2	162.13
19600.	.54047	.4677	265.8	5.994	5.053	84.361	-39.41	.9981	28.770	256.6	172.46
19400.	.54413	.4717	266.2	5.994	5.097	89.458	-39.07	.9877	30.508	257.0	182.88
19200.	.54778	.4756	266.6	5.994	5.141	94.598	-38.74	.9774	32.262	257.4	193.38
19000.	.55144	.4795	267.0	5.994	5.185	99.783	-38.41	.9671	34.031	257.7	203.97
18800.	.55519	.4835	267.4	5.993	5.230	105.013	-38.08	.9570	35.815	258.1	214.66
18600.	.55895	.4876	267.8	5.993	5.275	110.289	-37.75	.9470	37.615	258.5	225.43
18400.	.56270	.4916	268.2	5.993	5.321	115.610	-37.42	.9370	39.430	258.9	236.30
18200.	.56646	.4957	268.6	5.992	5.367	120.978	-37.10	.9271	41.261	259.2	247.25
18000.	.57021	.4997	269.0	5.992	5.414	126.392	-36.78	.9172	43.108	259.6	258.30
17800.	.57406	.5039	269.4	5.992	5.461	131.853	-36.46	.9075	44.971	260.0	269.44
17600.	.57791	.5081	269.8	5.991	5.293	137.146	-39.10	1.0508	46.850	260.3	280.68
17400.	.58176	.5122	270.2	5.991	5.138	142.284	-38.75	1.0385	48.672	260.7	291.59
17200.	.58561	.5164	270.6	5.991	5.185	147.469	-38.40	1.0268	50.440	261.1	302.20
17000.	.58946	.5206	271.0	5.991	5.232	152.700	-38.06	1.0151	52.224	261.5	312.89
16800.	.59341	.5249	271.4	5.992	5.279	157.979	-37.71	1.0036	54.024	261.9	323.69
16600.	.59736	.5292	271.8	5.992	5.327	163.306	-37.37	.9921	55.840	262.3	334.57
16400.	.60131	.5336	272.2	5.992	5.376	168.682	-37.03	.9806	57.673	262.7	345.55
16200.	.60526	.5379	272.6	5.991	5.425	174.107	-36.70	.9691	59.523	263.0	356.63
16000.	.60921	.5422	273.0	5.991	5.475	179.582	-36.36	.9577	61.390	263.4	367.80
15800.	.61326	.5467	273.4	5.991	5.526	185.108	-36.03	.9464	63.274	263.8	379.07
15600.	.61731	.5512	273.8	5.991	5.577	190.685	-35.69	.9351	65.175	264.2	390.44
15400.	.62136	.5556	274.2	5.990	5.630	196.315	-35.36	.9238	67.095	264.6	401.91
15200.	.62541	.5601	274.6	5.990	5.683	201.998	-35.03	.9125	69.032	264.9	413.49
15000.	.62946	.5646	275.0	5.989	5.736	207.734	-34.70	.9012	70.987	265.3	425.16
14800.	.63361	.5692	275.4	5.989	5.791	213.525	-34.37	.8900	72.961	265.7	436.95
14600.	.63776	.5738	275.8	5.988	5.847	219.372	-34.04	.8788	74.954	266.0	448.83
14400.	.64192	.5784	276.2	5.987	5.903	225.275	-33.72	.8676	76.965	266.4	460.83
14200.	.64607	.5830	276.6	5.987	5.961	231.236	-33.39	.8564	78.997	266.7	472.94
14000.	.65022	.5876	277.0	5.986	6.019	237.255	-33.06	.8452	81.048	267.1	485.16
13800.	.65448	.5924	277.4	5.985	6.079	243.334	-32.74	.8340	83.119	267.4	497.48
13600.	.65874	.5972	277.8	5.984	6.140	249.473	-32.41	.8229	85.211	267.8	509.93
13400.	.66299	.6019	278.2	5.983	6.201	255.675	-32.09	.8117	87.323	268.1	522.49
13200.	.66725	.6067	278.6	5.982	6.264	261.939	-31.76	.8005	89.457	268.5	535.17
13000.	.67151	.6115	279.0	5.981	6.328	268.268	-31.44	.7893	91.613	268.8	547.97
12800.	.67587	.6164	279.4	5.980	6.394	274.662	-31.12	.7781	93.791	269.2	560.90
12600.	.68024	.6213	279.8	5.979	6.461	281.123	-30.79	.7669	95.991	269.5	573.95
12400.	.68460	.6263	280.2	5.978	6.529	287.652	-30.47	.7557	98.214	269.9	587.13
12200.	.68897	.6312	280.6	5.977	6.599	294.251	-30.14	.7444	100.461	270.2	600.43
12025.	.69277	.6355	280.9	5.977	6.810	300.062	-29.86	.7346	102.440	270.5	612.26

Table E1. ALBS Balloon Inflation Calculations

$\Sigma \Delta L$ (lb)	W_s (lb)	V_B ft^3	d_B (ft)	$(C_DS_0)_S$ (ft^2)	$(C_DS_0)_B$ (ft^2)	D_B (lb)	D_D (lb)	D_M (lb)
	1770.00			1419.31				
8.87	1761.13	300.242	8.31	1446.41	27.10	33.00	412.35	1318.78
17.73	1752.27	595.900	10.44	1462.12	42.81	51.30	405.87	1295.10
26.72	1743.28	891.906	11.94	1475.32	56.01	66.18	400.18	1276.92
35.81	1734.19	1187.126	13.14	1487.08	67.77	79.04	394.94	1260.21
45.00	1725.00	1481.415	14.14	1497.86	78.56	90.47	390.02	1244.51
54.28	1715.72	1774.713	15.02	1507.92	88.61	100.82	385.33	1229.57
63.65	1706.35	2066.313	15.80	1517.38	98.07	110.28	380.84	1215.23
73.10	1696.90	2356.724	16.51	1526.36	107.05	119.01	376.50	1201.38
82.65	1687.35	2645.971	17.16	1534.95	115.64	127.12	372.29	1187.94
92.28	1677.72	2934.074	17.76	1543.20	123.89	134.69	368.18	1174.84
102.00	1668.00	3221.061	18.32	1551.15	131.84	141.78	364.18	1162.06
111.80	1658.20	3506.015	18.85	1558.82	139.51	148.40	360.25	1149.54
121.70	1648.30	3789.792	19.34	1566.25	146.94	154.64	356.41	1137.26
131.67	1638.33	4072.444	19.81	1573.47	154.16	160.51	352.62	1125.19
141.74	1628.26	4354.011	20.26	1580.49	161.18	166.05	348.90	1113.31
151.89	1618.11	4634.537	20.69	1587.34	168.03	171.29	345.23	1101.59
162.13	1607.87	4912.879	21.09	1594.00	174.69	176.21	341.61	1090.05
172.46	1597.54	5189.535	21.48	1600.50	181.20	180.86	338.04	1078.64
182.88	1587.12	5465.464	21.85	1606.87	187.56	185.26	334.50	1067.37
193.38	1576.62	5740.413	22.22	1613.11	193.80	189.42	331.00	1056.20
203.97	1566.03	6014.431	22.56	1619.23	199.92	193.35	327.54	1045.14
214.66	1555.34	6286.004	22.90	1625.20	205.89	197.04	324.11	1034.19
225.43	1544.57	6556.644	23.22	1631.07	211.76	200.53	320.70	1023.33
236.30	1533.70	6826.414	23.54	1636.84	217.53	203.83	317.33	1012.55
247.25	1522.75	7095.363	23.84	1642.52	223.21	206.93	313.97	1001.85
258.30	1511.70	7363.541	24.14	1648.11	228.80	209.86	310.63	991.20
269.44	1500.56	7628.878	24.42	1653.57	234.26	212.58	307.33	980.65
280.68	1387.32	7893.441	24.70	1320.29	239.65	251.81	0.00*	1135.51
291.59	1376.41	8145.379	24.96	1325.36	244.72	254.14	0.00	1122.27
302.20	1365.80	8386.657	25.21	1330.15	249.51	256.20	0.00	1109.61
312.89	1355.11	8625.516	25.44	1334.89	254.24	258.09	0.00	1097.01
323.69	1344.31	8862.603	25.68	1339.53	258.88	259.81	0.00	1084.81
334.57	1333.43	9099.250	25.90	1344.11	263.47	261.38	0.00	1072.05
345.55	1322.45	9335.514	26.12	1348.66	268.01	262.80	0.00	1059.65
356.63	1311.37	9571.441	26.34	1353.15	272.51	264.09	0.00	1047.28
367.80	1300.20	9807.078	26.56	1357.61	276.96	265.25	0.00	1034.95
379.07	1288.93	10039.533	26.77	1361.97	281.32	266.24	0.00	1022.69
390.44	1277.56	10271.711	26.97	1366.29	285.64	267.09	0.00	1010.47
401.91	1266.09	10503.669	27.17	1370.57	289.93	267.82	0.00	998.26
413.49	1254.51	10735.458	27.37	1374.82	294.18	268.43	0.00	986.08
425.16	1242.84	10967.124	27.57	1379.04	298.39	268.92	0.00	973.91
436.95	1231.05	11196.356	27.76	1383.18	302.54	269.26	0.00	961.79
448.83	1219.17	11425.515	27.94	1387.30	306.65	269.49	0.00	949.68
460.83	1207.17	11654.660	28.13	1391.38	310.74	269.60	0.00	937.57
472.94	1195.06	11883.842	28.31	1395.44	314.80	269.59	0.00	925.47
485.15	1182.85	12113.111	28.49	1399.46	318.83	269.48	0.00	913.37
497.48	1170.52	12338.770	28.67	1403.43	322.78	269.21	0.00	901.30
509.93	1158.07	12564.551	28.84	1407.35	326.71	268.84	0.00	889.23
522.49	1145.51	12790.818	29.02	1411.26	330.61	268.38	0.00	877.15
535.17	1132.83	13016.717	29.19	1415.14	334.50	267.77	0.00	865.06
547.97	1120.03	13243.213	29.35	1419.01	338.37	267.07	0.00	852.95
560.90	1107.10	13467.000	29.52	1422.81	342.17	266.24	0.00	840.86
573.95	1094.05	13691.148	29.68	1426.60	345.96	265.31	0.00	828.74
587.13	1080.87	13915.726	29.84	1430.37	349.73	264.28	0.00	816.60
600.43	1067.57	14140.793	30.00	1434.13	353.49	263.14	0.00	804.43
612.26	1055.74	14339.811	30.14	1437.44	356.80	262.05	0.00	793.69

LEGEND

H	Altitude
σ	atmospheric density ratio (ρ/ρ_0)
P	atmospheric pressure
L/M ratio	Lift/Mass ratio lb. lift/lb. gas
Δt	time differential
$\Sigma \Delta t$	cumulative differential
V_e	system equilibrium descent velocity
q	dynamic pressure
$\Sigma \Delta M_{He}$	Cumulative quantity of Helium transferred
$\Sigma \Delta L$	Cumulative buoyancy added to system
W_s	overall system loading on parachutes
V_B	Volume of gas bubble
d_B	diameter of gas bubble
$(C_DS_0)_S$	total effective drag area
$(C_DS_0)_B$	Effective drag area of gas bubble (balloon)
D_B	Drag of balloon
D_D	Drag of Drogue
D_M	Drag of Main Chute

Note 1. $D_B + D_D + D_M = D_S = W_S$ at Equilibrium Velocity

*Drogue Cut-away Point